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AT HARVARD COLLEGE.

VOL. LVI. NO. 1.

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GEOLOGICAL EXPEDITION TO BRAZIL AND CHILE, 1908–1909.

BY J. B. WOODWORTH.

WITH THIRTY-SEVEN PLATES.

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Reports on the Scientific Results of the Expedition to the Eastern Tropical Pacific, in charge of Alexander Agassiz, by the U. S. Fish Commission Steamer "Albatross," from October, 1904, to March, 1905, Lieutenant Commander L. M. Garrett, U. S. N., Commanding, published or in preparation:—

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[1] Bull. M. C. Z., Vol. XLVI., No. 4, April, 1905, 22 pp.
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[3] Bull. M. C. Z., Vol. XLVI., No. 9, September, 1905, 5 pp., 1 pl.
[4] Bull. M. C. Z., Vol. XLVI., No. 13, January, 1906, 22 pp., 3 pls.
[5] Mem. M. C. Z., Vol. XXXIII., January, 1906, 90 pp., 96 pls.
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[14] Bull. M. C. Z., Vol. XLIII., No. 6, October, 1908, 285 pp., 22 pls.
[15] Bull. M. C. Z., Vol LII., No. 5, October, 1908, 11 pp., 2 pls.
[16] Mem. M. C. Z., Vol. XXXVII., February, 1909, 243 pp., 48 pls.
[17] Mem. M. C. Z., Vol. XXXVIII., No. 1, June, 1909, 172 pp., 5 pls., 3 maps.
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[26] Bull. M. C. Z., Vol. LIV., No. 12, April, 1912, 38 pp., 2 pls.
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With Thirty-seven Plates.

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No. 1.— *Geological Expedition to Brazil and Chile, 1908–1909.*

By J. B. Woodworth.

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I. PREFATORY NOTE TO THE SHALER MEMORIAL SERIES.

The late Dean Shaler, at first Professor of Palaeontology and later Professor of Geology at Harvard University, during his long career as naturalist and teacher, both by his writings and his teaching, displayed a very wide interest in the various aspects of the earth's sciences. When in commemoration of his long services to the University a group of over seven hundred of its alumni raised an endowment of more than $30,000. for the purpose of maintaining and publishing the results of investigations suitable to his memory, the Division of Geology, to which this gift was entrusted, found itself provided with a fund for the advancement of knowledge in the entire field of its scope.

The following are the terms governing the use of the Shaler Memorial Fund (see the letter of gift in the Annual Report of the Curator of the Museum of Comparative Zoölogy for 1906–07, Cambridge, 1908, p. 19–20).

"The researches here contemplated are to be undertaken by persons nominated by the Committee of the Division of Geology and appointed by the Corporation, whether officers or students of Harvard University or not. The subject and the locality or field of research are to be approved by the

Division Committee, preference being given to studies of an advanced and original character. The sums of money allotted from the income for research are to be determined by the Division Committee with the approval of the Corporation. The money appropriated for such work from the income of the fund shall be in addition to the salary that would be otherwise paid to the person or persons undertaking it; and any work or journey thus supported in whole or in part shall be carried on under the name "Shaler Memorial Research" or "Shaler Memorial Expedition."

"The publications here contemplated are to include the results of original research carried on with the income of the fund, or independently of such aid; but the results must in all cases receive the approval of the Division Committee as to subject and presentation — though not necessarily as to the conclusions stated — before they are accepted for publication.

"All publications thus approved, whether appearing in independent volumes or in some established journal, shall bear the general title, "Shaler Memorial Series." The allotment of money for publication shall be determined in the same way as for research.

"Beneficiaries under the fund, either as to research or publication, may be invited by the Division Committee to give one or more public lectures in Cambridge on the results of their studies, under the general title "Shaler Memorial Lectures," but no additional payment is to be made for these lectures.

"The income of the fund may be allowed to accumulate in case an investigation, expedition, or publication of considerable magnitude is contemplated by the Division Committee, but it is not desired that such accumulation shall continue beyond a reasonable period of time."

In geology, the action of volcanoes, the phenomena of the contact of sea and land, and the evidences of past glaciation particularly occupied Professor Shaler's thoughts. This last subject was a direct inheritance from his master Louis Agassiz. With James Croll, Professor Shaler went further than Louis Agassiz did in perceiving evidences of glacial periods in the geological record long anterior to the great ice-age whose recognition was the lasting contribution of Louis Agassiz to geological science. Professor Shaler anticipated the discovery in the conglomeratic formations of the closing Palaeozoic era of signs of glaciers, which only in recent years have been thoroughly scrutinized by others and found to be veritable products of glacial action. With a view to contributing to the advancement of knowledge in this field, the Division of Geology voted that a grant of money from the Shaler Memorial Fund be expended by the author for the exploration of the Permian conglomerates of the region south of São Paulo in Brazil, the glacial origin of which had already been advanced by Dr.

Orville A. Derby. The report herewith submitted is the result of that expedition. After the rainy season had begun in Brazil, I devoted the time at my disposal to a brief examination of the changes of level on the coast of southern Chile.

Other investigations will be undertaken from time to time as the state of the fund may warrant expenditures.

II. INTRODUCTION.

In presenting the itinerary of portions of the region traversed, I have taken the most convenient way of recording numerous observations not pertinent to the main object of the journey. Some of the phenomena dealt with in this report have long been described in other languages but without much discussion of causes or of geological correlation. On this account I have been led into a free exercise of the geologist's privilege, if not his proper task,— to interpret his observations and in the language of Robert Hooke "to raise a chronology out of them." The chapter on the Triassic trap plateau presents the results of a rapid reconnaissance of a little known geological field quite unfamiliar to North American students, and the account of the topographic relief of south Brazil is a sketch *en route* embodying observations in a more systematic order than as if left to discrete and unrelated paragraphs in an account of scientific travel.

Through the courtesy of Dr. Orville A. Derby, the recently appointed Director of the Mineralogical and Geological Service of Brazil it was arranged to conduct the Shaler Memorial party to the glacial boulder-beds of Paraná. To further facilitate the work of the expedition Dr. Euzebio Paulo de Oliveira, Assistant geologist of the Service, was detailed by the Director to act as "interpreter, guide, and friend." We were met by Dr. Oliveira on the confines of Paraná where I found him engaged in making a geological map of the state. The generous conduct of this young geologist in placing freely at my disposition the results of his observations upon the distribution of the strata and in allowing me to examine his collections of rocks and fossils makes me much indebted to him for many of the facts presented in this report. With him and his pack-train I made the expedition across the trap plateau from Rio Negro to Lages and later he made with me the excursion up the valley of the Rio Tuberão in Santa Catharina. Throughout these journeys the transportation was supplied by the Brazilian Survey. Without this financial assistance the work could not have been carried so far, and without the guidance

afforded by Dr. Derby and his coadjutor many of the best localities would not have been found in the short time that was at my disposal.

Dr. João Cardoso, the Director of the Geological and Geographical Commission of São Paulo kindly detailed Dr. Pacheco, Geologist of that survey to accompany me on the trip from Itaicy to Piracicaba in that state and to Dr. Pacheco's acquaintance with that region I owe much.

In Chile, as a delegate of Harvard University to the Pan-American Congress held in December, 1908, I was accorded free transportation on the government railways through the courtesy of the Director of railways, a privilege which I exercised in the journey from Concepcion to Valdivia and return to Santiago and thence eventually to Valparaiso Special rates were also given in the passage on the Chilean steamer *Limari* from Valparaiso to Panama; both of these favors reduced the expenses of the Shaler Memorial Expedition.

Prof. Robert DeC. Ward of Harvard University was appointed a member of the Expedition to carry on studies in climatology and to gather material for a course on the geography of South America. He accompanied me as far as Ponta Grossa in Paraná, whence he journeyed to Paranagua, going by steamer to Santos, thence by rail to São Paulo, and so to Rio de Janeiro, from which port he took ship for New York in August, 1908. The more important publications resulting from his investigations are listed on p. 137.

Mr. Winthrop P. Haynes, an undergraduate student in the University, was appointed Assistant in geology and accompanied me at his own expense as far as Ponta Grossa and Paranagua, whence he also returned to the United States in August, 1908. He aided in the collection of rocks and fossils in northern Paraná.

I have retained the Portuguese spelling of the Brazilian names used in the text. The pronunciation of these is similar to the Spanish but the following peculiarities should be noted: — *Ch* is regularly and *x* ordinarily equivalent to *sh* in English; *g* soft before *e* and *i* is like the French *j*. Words ending in *am* and *ão* have Portuguese nasal sounds in which the nasal *a* is pronounced somewhat as *ou* in *out* with the lips slightly closed at the end as if to give the letter *m*. Likewise names ending in *im* are nasalized like *ing* in English but with the final *m* sound slightly given.

III. ITINERARY.

"The usual bane of such expeditions is hurry; because men seldom allot themselves half the time they should do: but, fixing on a day for their return, post from place to place, rather as if they were on a journey that required dispatch, than as philosophers investigating the works of nature."

Gilbert White. *The Natural History of Selborne.* Letter XXVI, December 8, 1769. London: 1789, p. 73.

The first Shaler Memorial Expedition following a generation after the Thayer Expedition to Brazil sailed from New York for Rio de Janeiro on the 20th of June, 1908, on the Steamship *Voltaire* of the Lamport and Holt Line. As previously stated the party consisted of Professor Ward, Mr. W. P. Haynes, and the author in charge. The ship touched at Bahia on July 5th, and reached Rio de Janeiro on the 8th of that month.

On this lonesome tract straight out from the North American coast at New York to Cape St. Roque the voyageur sights few vessels. The minor changes of a June and enjoyable sea, the endless piles of trade clouds, a solar annual eclipse — that of June 28th, — the first view of the Southern Cross, the doldrums and their rains, the so-called "green ray" of the setting sun,— these were the events of the voyage of the *Voltaire* for those members of the party who made their first crossing of the equatorial line.

At Rio de Janeiro we were met and taken care of by Dr. Orville A. Derby, Director of the Mineralogical and Geological Service of Brazil, and under his tutelage began preparations for the journey to the planalto of south Brazil. Our stay in the Capitol was somewhat lengthened by the necessity of awaiting the discharge of Mr. Haynes from the English Hospital, to which institution he had been obliged to go for the treatment of an infected bruise received on shipboard. At this time and indeed through my stay in Brazil, the Capitol suffered greatly from an epidemic of small-pox. According to reports given out on leaving the country as many as 6,722 deaths were caused by this disease in Rio de Janeiro between January 1st and November 22nd, 1908.

During this interval I visited Petropolis from which point under the guidance of Dr. Miquel Arrojado Ribeiro Lisboa an excursion was made to the valley of the Piabanha and the picturesque Valle do Retiro (see Plate 1), a characteristic portion of the eroded coastal

Fig. 1. — Route map of the Expedition from New York to South America and return.

border of the Brazilian tableland constituting the so-called Serra do Mar.

Many maps of Brazil published in that country bear lines of longitude reckoned from the position of the National Observatory in Rio de Janeiro, which lies in 43° 10′ 21.15″ West Long. from Greenwich. The only high-grade maps, outside of certain municipal contoured maps, have been published by the Comissão Geologica e Geographica de São Paulo. Old-fashioned hachured maps of the topography exist for some states but they are all inadequate for the purpose of geological mapping The territory of Brazil is vast and the interior so little developed that it cannot be expected that the general government can undertake, at present, the making of such maps of its domain as exist for several of the European states, or even a map of the serviceable character of the topographic map of the United States of America. In the case of the state of Paraná I was not able to procure in published form, even an approximately accurate map though a very useful manuscript map is in existence to which I had access. The small-scale map of Santa Catharina published by the State is fairly good for exploratory work. The best general map of São Paulo is that of Williams.

Of the geological text-books which circulate mostly in Brazil, owing to the higher education being based largely on the system of the French, there are several editions of the elementary hand-book of the late Professor de Lapparent. A Portuguese translation by Dr. B. F. Ramiz Galvão, of the third edition of the elementary text, entitled Resumo de Geologia, with appendices relating to the geology of Brazil by Dr. Derby, is much used in the schools where geology is taught. Prof. John C. Branner published in 1906 an elementary geological text written in Portuguese with special reference to Brazilian students and embellished with illustrations from native sources including cuts of South American fossils.

The National Exposition at Rio de Janeiro in 1908, held to commemorate the centenary of the opening of the ports of the country, resulted in the bringing together of a collection of rocks and minerals from many parts of this vast territory. Most of these exhibits were intended to set forth the economic resources of the several states. The best of these state collections was that from São Paulo formerly under the directorship of Dr. Derby. From the new territory of Alto Acre there was a small collection of rocks including a dark pebbly sandstone locally used for whetstones, ferruginous sandstone, and a fragment of an ironstone concretion, incorrectly labelled as an aerolite!,

gypsum, and samples of clay. From Piauhy there were bottled sulphurous mineral waters, talc, kaolin, graphite, concretionary hematite, and fossil wood. From Sergipe, crystalline limestone and a compact, light-colored argillite used for construction. From Ceará, porphyritic granite, a red granite coarsely crystalline, fossil cetacean bones from Cruxatú, copper carbonate from Milágres, concretions with fossil fishes, and tile work. Alagoas sent pottery products, particularly water-jars made from the clay of Penedo on the Rio Francisco, noted for their porosity and consequent evaporating capacity and cooling power, the most preferred carafes in Brazil. The exhibit also included granites and marbles, among the latter a dark and light-banded crystalline crumpled variety; garnets and black tourmalines. From Rio Grande do Norte, there were soapstone, beryl, and aquamarines; Cretaceous and Tertiary limestones; yellow bricks, salt from the evaporating pans of Caico and Macau, and gypsum from Carambas. Rio Grande do Sul exhibited bituminous coal from the Permian; agates from the Triassic trap sheets; wolframite from Rio Pardo; cuprite, indigolite from Bagé; molybdonite, covellina, native copper from Colonia militar; tin ore; besides artificial stone-ware and colored tiles. From the state of Pará, the exhibits consisted chiefly of clay products, such as bricks and drainpipes from Cametá and Belem. From Matto Grosso there were gold and diamonds from Coxipo mirim; diamonds and sapphire gravel from the Rio Coxim; gold and diamonds from a basal conglomerate beneath a Devonian sandstone; besides ores of manganese, hematite, and exhibits of limestones. The state of Amazonas was represented by gneisses and schists, silicified wood, artificial stone-ware, tiles and bricks manufactured from Tertiary clays. Goyaz furnished muscovite in merchantable plates, gold, galena, amethyst, rutile, diamonds, yellow quartz (now exported), rose quartz, limonite, soapstones, and millstones. Maranhão had an exhibit of gold. Bahia supplied a collection of minerals, including manganese from Napareth, muscovite from Conquista (said to exist in commercial quantities), monazite sands from Prado, tabatinga (ochreous clays of a variety of colors), copper carbonate from Bom Fim, manganese, limestone, a fine compact brownish limestone with a tendency to a shelly fracture and often horizontally banded from Campo Formoso; granites and gneisses, including a red gneissoid granite from Jacaricy, talc blocks from Caruanyba, lithographic (*sic*) limestone from Carinhanha and Bom Jardim; clay products, including red porous water-jars. The state of Santa Catharina furnished exhibits of the Permian coal, manganese

from Itajahy, molybdenite from Morro do Bahú, magnetite, ochres, slates, and the products of a newly established cement industry. Minas Geraes (the state of "general mines") exhibited of ordinary minerals manganese, itabarite from the well-known peak, micaceous hematite, limonite ores, and clay products from Bello Horizonte; but the most striking exhibit was made by the Morro Velho Mine which, in addition to a rich display of ore, put on exhibition a model showing the working of the ore shutes, the shafts, and levels, with a suitable explanation, in itself the most complete exhibit in the collection.

The newly established federal survey exhibited a relief map of the vicinity of Rio de Janeiro and an excellent series of enlarged photographs illustrative of types of Brazilian rocks and landscapes.

There is a great abundance of manganese in Brazil and from reliable reports received then and since it is most probable that Brazil is destined to be a producer of iron on a large scale and owing to the belated resort to these deposits will enjoy prosperity from this resource when the workable ores of the United States have been exhausted.

Our party left Rio de Janeiro on *July 22nd*, for São Paulo. The points of geological interest on the line of the railway include Mt. Tingua among the lower peaks of the Serra do Mar, which furnished the dikes of phonolite consisting of an alkali feldspar, nepheline, and aegirine to which rock Rosenbusch (Hunter and Rosenbusch, 1890) gave the name tinguaite. A good view of the black mountain may be obtained from Ottoni Station. On passing the crest of the Serra and attaining the valley of the Parahyba the Serra da Mantiqueira comes into view, culminating in Mt. Itatiaia, a mass of nepheline-augite syenite or phonolite, the loftiest point in Brazil, 2,994 meters (9,493 ft.), and the highest in South America outside of the Andes. Its summit is a bare rock with weathered out joint-structure forming needles on a large scale. It is plainly seen from Rezende Station. H. H. Smith (1879, p. 441) states that snow occasionally covers the summit.

The Tertiary deposits in the valley of the Parahyba are followed for many leagues by the railway. In the dry season the train in traversing these plains stirs up a fine reddish dust which penetrates the closest cars.

Near Pindamonhangaba Station I noticed two or three broad shallow lakelets in the weathered surface of the rock, a type of basin which abounds in the old weathered surface of Brazilian rocks.

At Taubaté Station an oil shale is distilled from the Tertiary beds, and Dr. Derby states that peat deposits occur near this place.

July 23rd.— The day was spent in São Paulo. At the office of the Geological and Geographical Commission of the state there is to be seen a unique collection of fossil silicified wood from the Permian northwest of the city and some skeletons of Stereosternum, a reptile occurring in the upper Permian. Among the sections of a diamond drill recently obtained from a boring in the Permian strata I detected a glaciated pebble with well-defined striae in a blue tillite bed, a discovery which at once promised much for the objects of the expedition. An excursion was made to the vicinity of the American College for the purpose of studying the *terra roxa* which in the state of São Paulo plays so large a role in the cultivation of the coffee plant.

July 24th.— We left São Paulo at an early hour by the Sorocabana railroad for the end of the line at Bury. At São Roque the line enters a valley with outcrops of slates and limestones, an apparently infolded member of the Pre-Devonian terrane of which the gneisses and schists of the Serra do Mar region are the most ancient parts. The railway follows along the contact of the limestone with granite as far as Mayrink Station, beyond which town the slate belt is followed. Beyond Pantoja Station a blue limestone crops out and kilns have been built for making lime. Slates and limestones continue along the route to Rodovahlo Station, where there is a cement factory. From Pyragibu to Sorocaba the road leaves the belt of metamorphosed sediments, and passes over granites and gneisses. The disintegration of the porphyritic granite, as pointed out by Dr. Derby, produces the granitic surface sands known as *sumarão*, while weathering of a deeper sort changes the granites and gneisses to a clay which from its habit of balling under the shoe is called *massa pé.*

From Sorocaba onward to Bury the route lay over the Permian area of sandstones, shales, and intercalated tillite beds. The line passes within sight of the Ypanema stock some three miles in diameter forming a slight elevation above the general level and mainly composed of eruptive rocks in the Pre-Permian terrane. The igneous mass is a nepheline syenite with segregations of magnetite famous for its early use as an iron ore. Ferreira says the ore was discovered in 1578. At Ypanema there are quarries in a grey sandstone of the Permian, and old iron furnaces, perhaps the site of the earliest production of iron in America.

Throughout the day the mainly open unwooded campos of the upland, or planalto as the Brazilians term the slightly accidented

surface of the plateau, was the striking feature in the landscape. Long round swells or hills with graceful curves to the stream ways betokened everywhere the long continued action of erosion. The excellent topographic maps of this portion of the state by Mr. Horatio Williams begun by the Geological and Geographical Commission of São Paulo under the directorship of Dr. Derby made it possible to follow the route intelligently and interpret the general outlines of the erosive history of the district. In a following chapter on the geomorphology of the region, I have made free use of these maps.

July 25th.— In 1908, the passenger service of the railway terminated at Bury, but a line in process of construction extended the communication by rail to Ponta Grossa in Paraná, and so into connection with points on the south far towards the boundary of Uruguay. As will be shown in the sequel the fresh cuttings of the rocks and surface deposits along this new line afforded an exceptional opportunity to study the geology not only of the underlying Permian tillite beds but also of the superficial gravels and their cover of red earths variously known as *terra roxa*, etc. This day we proceeded on a flat car some 18 kilometers along the line of construction, completing the journey to Faxina by a sort of carriage known as a "trolley." While traversing the high campos a hailstorm came up from the west with a well-defined horizontal vortical ring of black clouds, from which hail associated with rain fell so as to coat the ground with hailstones. For nearly an hour after the passage of the storm the small streams now in flood carried a thick load of hailstones. This fall of hail within the subtropical region at an elevation of 900 meters above the sea suggested an inquiry as to the occurrence of hail at lower elevations nearer the equator as a possible factor in the Permian glaciation since it appears that in this way ice may be precipitated in regions where snow never falls.

July 26th.— Being unable to secure a conveyance to Itararé, the day was spent in Faxina. This town is underlain by the Devonian sandstone, a light colored to whitish rock, with cross-bedded layers, and occasional bands of white quartz pebbles. Nodules of clay occur also embedded in the sandstone. The strata are well exposed in a ravine on the outskirts of the town.

July 27th.— Having procured the means for the conveyance of our party to São Pedro de Itararé on the boundary of Paraná, we journeyed to that place. For most of the day the route lay over the Permian basal sandstones which appeared in the stream bottoms, sometimes with thin beds of white quartz pebbles but without trace of compound

conglomerates such as constitute the tillite beds. Some of the coarse gritty beds contained clay particles. In all probability these were once grains of feldspar indicating that the unaltered rock was a granitic sandstone related to arkose. Dikes or sills of basic intrusives occasionally intersect the sandstone along this route.

July 28th.— Through the courtesy of Dr. Cruz Lima we travelled in a special car from Itararé to Jaguariahyva, stopping in the newly opened railway cuts to examine the tillite beds. At the first stop in a cut above the Rio Jaguaricatu in Paraná a well-striated pebble was found in a boulder-bed, establishing at once the identity of origin of these deposits with those of India and South Africa.

July 29th.— Continued the journey by rail to Ponta Grossa, the headquarters of the party engaged in the geological survey of Paraná.

The railway from Jaguariahyva to Ponta Grossa crosses the Devonian sandstone cuesta affording a magnificent view of the country.

Between Pirahy and Coxambú the Pre-Devonian rocks, exposed in a lowland widened out along the course of the Rio Yapo, comprise a tilted group of rocks of which I have seen no account in the descriptions of the metamorphosed district of the Serra do Mar. At Pirahy Station there is a monoclinal set of beds in a ridge west of the railroad. The beds strike north by east and dip about 30° west. About a mile south of Pirahy at a water-tank a felsitic breccia crops out. Farther south the train passes through a cut in which slightly metamorphosed shales, sandstones, and a pebble bed with fragments of red felsite, granite, etc., appear, having a reddish color and dipping westward at an angle of about 30 degrees. These rocks from their relatively unmetamorphosed condition appear to be younger than the belt of slates and limestones described as occurring in São Paulo. No fossils were seen in the section nor did time permit a satisfactory search for further details of the stratigraphy. This formation, so different from the members of the Pre-Devonian terrane on the east, is the most western member of the highly inclined rocks seen in Paraná and suggests that some horizon between the Middle Devonian and the slate and limestone terrane may yet be worked out and correlated in this field.

Several days were spent at Ponta Grossa in the examination of the surrounding country, including a visit to Conchas where a bed of tillite is to be seen. In the Carboniferous sandstones west of Ponta Grossa I found some worm burrows of the type known as Monocraterion; these show a cup-shaped superior termination and a vertical

tube penetrating to the bottom of the layer, some five inches in thickness. The tubes were filled with a fine greenish shale. (Fig. 2.) Similar burrows occur in Pennsylvania in the Ordovician (J. P. Lesley, '89, **1**, p. 417–418) but seemingly are of no diagnostic value in determining the age of the strata in which they occur. It is possible that the cup at the orifice of the tube in Monocraterion is due to the caving in of the sands prior to their covering by the superincumbent layer, and that thus it is not to be taken as showing the form of the anterior portion of the animal which made the burrow.

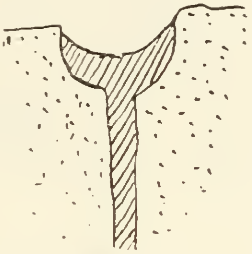

FIG. 2.— Monocraterion sp. A worm burrow occurring in Permian sandstones on the banks of Lageado grande near Ponta Grossa, Paraná.

From Ponta Grossa an excursion was made under the guidance of Dr. Derby to Curityba and thence to the coast at Paranagua. An excellent view of the profile of the plateau and the Serra do Mar was obtained and I have utilized the data in what follows on the geomorphology of south Brazil. From Ponta Grossa also I set out for a trip via Rio Negro, over the trap plateau to Lages in Santa Catharina. As the itinerary of this expedition includes some observations upon the general character of the country not embodied in North American geographical writings, I have transcribed this portion of my Journal with but slight condensation.

A Journey from Rio Negro to Lages and return to Porto da União on the Iguassú. It having been decided to make a reconnaissance of the section from Serrinha on the upper waters of the Iguassú to Rio Negro and thence southwards to the base of the Triassic escarpment, the traverse was continued southwards to Lages. The Triassic formation was examined for any evidence which might have a bearing on the transition period following that of Permian glaciation. Dr. Euzebio Paulo de Oliveiro and myself set out from Ponta Grossa on August 13 by rail for Rio Negro, the end of the railway, making stops at Tamanduá, Serrinha, and Lapa. A synopsis of my notes on the geology of this portion of the route is embodied in ensuing chapters on the Permian deposits. See Plate 13 for map of route.

At Rio Negro we heard of the Bugres, wild aborigines who infest the trap escarpment on the south and often ambush lonely travellers on the pass over the Serra do Espigão. Southwest of this high point along the Serra Geral there is a remnant, so I was informed, of the

Botocudos, whose haunts are carefully avoided by Brazilian travellers. These naked savages sometimes commit outrages on the new Euro-

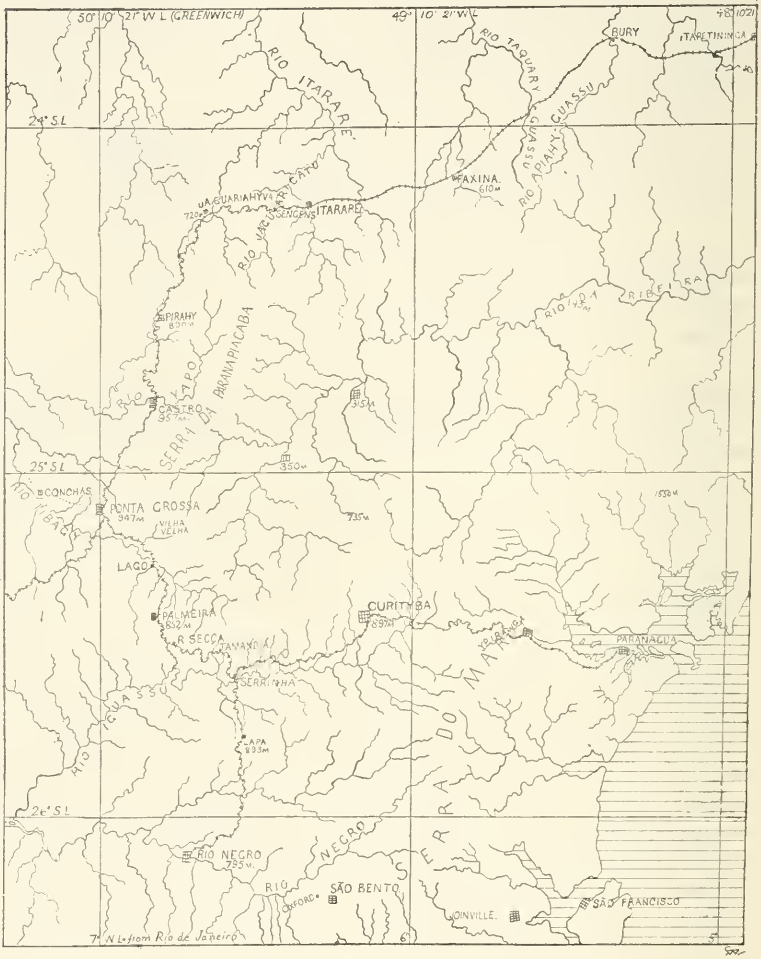

Fig. 3.— Sketch map of eastern Paraná showing localities visited by J. B. Woodworth.

pean settlers who have colonized the lands back from the old occupied sites of the coast. It seems strange to the visitor from North America to find here within a hundred miles of the Atlantic coast conditions

of European settlement such as characterised the period of the first third of the 18th century in the New England states and New York. The topography of this portion of Brazil, its inaccessibility, and the inutility to the older inhabitants of European origin of a large stretch of country along the ragged escarpment of the trap plateau accounts in large part for this lingering of a hostile primitive people in close proximity to the coast; encouraged and abetted by a more or less easy communication for the untrammelled native by larger bodies of indigenous folk in the hinterland of Paraná, where, among the Coroadas savage life remains in yet greater exemption from the restraining influences of advancing civilization. The extension of the railway from Porta da União southward across the trap plateau divides these people and promises to bring to an end a frontier struggle which has endured too long.

Our pack-train having arrived at Rio Negro, we prepared for the expedition to Lages. The equipment for geological field work in this region is extremely simple. For the four members of our force, one light tent was provided, poles for which were cut from night to night in the forest surrounding our camp sites. The baggage was carried in wicker baskets or panniers lashed on pack-saddles. Our provisions consisted of prepared black beans, boiled rice, farinha meal, broad thin slabs of drief beef known as xarque, and a supply of powdered burnt coffee with which the proper quantity of sugar had been mixed. A few small pots and cooking basins completed the outfit. The business of camp life was equally simple. In the morning before mounting, black coffee and bread were served. Breakfast was eaten between 11 and 12 after a ride of a few hours, and a second substantial meal was prepared at night after establishing camp. Except for small supplies of corn (maize) obtained at long intervals at some farm house, the mules subsisted on the leaves of the bamboo and other tender foliage which they found along the route. Water and wood for the camp fire were everywhere in abundance.

August 17th.— There was a heavy white frost on the ground at Rio Negro at an early hour this morning. We set out promptly for the south, keeping track of the distance traversed by means of pedometers. A mule pace in Brazil is reckoned at 0.72 meters (2.36 ft.). The mule trail from Rio Negro to Lages traversing some thirty-six rivers and streams was cut through the forest in the middle of the 18th century as a military necessity (V. da Rosa, 1905, p. 265–266). As far as the Rio Laurenço, the route lies over shales and yellow pebbly sandstones carrying an occasional erratic block. Beyond

this point the road enters a heavily wooded district of moderate dissection with flat-topped interstream areas. We camped for the night near the road 2.3 miles south of a small settlement called Sepultura.

August 18th.— It was so cold at midnight that one of the camaradas made coffee with which we were served. At this hour a pan containing water was coated with a thin sheet of ice. From this camp to the Rio Contagem the route traverses a soft sandstone formation. Just before halting for breakfast at 10 a. m. we passed a shaded mud-puddle covered with a thin film of ice. These occurrences of frost and ice I note particularly because they were so contrary to my preconceived notions, based upon the imperfect accounts in North American geographies of the winter climate of even this elevated region in south Brazil. Apparently horizontal beds of deeply weathered sandstone continued to form the surface rock as far as camp No. 2 on the headwaters of a small stream, the Rio São João, a north flowing branch of the Rio Negro. The gentle descent from the plain to camp lay through a forest of Araucaria, tree-ferns, and a graceful bamboo with long curling tips.

August 19th.— The night was cold again, with frost on the ground and ice in the camp dishes at an early hour this morning. Shortly after leaving camp we traversed a plain with large areas of dead brakes, scattered palms, and tree-ferns. Araucaria is however the most abundant forest tree; there are large tracts of it, and many young trees are in evidence. For over a kilometer the path led through a dense growth of tree-ferns, taquara or bamboo, Araucaria, and large imbuias (*Canella imbuia* of Brazilian writers) with numerous mud-holes crossed-ridged with the pilões made by mules, through which our train of animals wallowed with extreme slowness. This jungle suddenly gave way to a wagon road on good ground, the sign of approach to some German or Polish settlement, of which however we saw nothing. Along this route we came upon a fine example of the tall Brazilian sassafras tree (*Nectandra cymbarum*), standing alone in the forest. Descending through swampy places of the wet-wood type we entered another forest of Araucaria. Tree-ferns partially hidden on the edge of these forests or standing in the more or less open growth of tall trees were in sight most of the day, but no rock exposures were seen and no pebbles bestrewed the trail which seems to have lain over decomposed shales. Here and there in the valley bottoms two or three huts were encountered, around which were pigs, a few sheep, cattle, and horses. We camped beside a stream on the soft spongy ground of tree-fern growth in the forest.

August 20th.— The night was cloudy with a little rain and consequently warmer than on the two previous nights. We found that we had gotten on to the road leading over the Serra do Espigão, the very route we meant to avoid because of the Bugres, but quickly resolved to keep on. After proceeding at a painfully slow pace with many uncertain turns through the forest we halted at a distance of not more than 3.2 kilometers for breakfast in a piece of open campo surrounded by the now dripping forest, our way having led over vales and ridges about 100 feet high and through tree-fern swamps. More native huts appeared at about 5 kilometers from last night's camp. At about 6 kilometers from the camp we encountered a chert bed on a hill south of a hamlet. Under this bed, at a river crossing immediately north, there outcrop green shales. We got into camp on the bank of a small stream the valley of which is excavated in a yellowish green shale. For an hour before reaching this camp, the flat sky-line of the Triassic escarpment could be seen ahead on the south. Some huts near camp were built of hewn boards and hand-made shingles, with the usual open windows. This place is Chaxim. There was a broken down cross and the remnants of a fence along side our camp, enclosing the burial place of some one killed by the Bugres. All travellers on this road we observed went armed, an example which we followed.

August 21st.— We got off early from camp as the manuscript map in our possession indicated that we were now near the base of the trap escarpment and should make the pass over the Serra do Espigão before noon. The road led over some low hills of greenish shale near the beginning of the ascent. Shortly before the climb began we came to a few houses south of Chaxim, at one of which, a store kept by a German, we found a bugreiro, or sort of special police, armed with a cavalry sword and a double-barreled horse-pistol, whose evident business it was to accompany parties over the pass. The ascent of this pass, only some 1,200 feet above our base at the store, was so steep as to oblige us to dismount, and was made in such a rush with all revolvers drawn, that geological observations were, despite the frequent exposure of ledges, neither advisable nor clearly made.

As is usual with South American mule paths the way led up the steep spur in preference to following one of the adjacent creases of the slope, since by so doing the minimum of mud and water is encountered at all times of the year. The escarpment below the crowning trap sheet is mainly sandstone of a reddish tinge which succeeds the green shales at the base. The chert beds before mentioned apparently

correspond with the Estrado nova shales of Dr. I. C. White, while the beds of sandstone in the face of the escarpment reddish below and light colored above correspond with his Rio do Rasto and São Bento beds respectively.

The trap crowned pass of the Serra do Espigão is separated from the main mass of trap on the south by ravines parallel with the escarpment, somewhat as in the annexed sketch of the profile. (Fig. 24, p. 93). The summit where crossed by the trail gave an aneroid reading of 3,950 feet. A new cross by the roadside at the southern side of the first ravine marked the spot where but a few weeks previous a Brazilian had been killed by the Bugres. Of these savages, however, we saw none nor were we molested. Our bugreiro left us at a point near the cross and returned to his post at the base of the escarpment. On passing the summit I noticed fresh ice crystal marks in a dried up mud-puddle. We descended at once the south slope of the ridge, passing the lower contact of the trap on the sandstones to an open campo watered by the Lageado liso, a small stream so named, in common with many in Brazil, from the flaggy beds in its channel and banks. The tilted attitude of a band of beds in the valley of this stream suggested faulting parallel with the escarpment, but I was not able to determine by the elevation of the base of the trap on the opposite side of the valley the occurrence of a displacement of this plane of reference, though it was my impression that the trap in the Serra do Espigão lay higher. From the Lageado liso the ascent is gradual but steadily upward to the top of a broad tableland of trap giving aneroid readings of 4,050 to 4,100 feet elevation some 6 kilometers south of the Lageado liso. At 8.6 kilometers some farm houses appeared about which were fields enclosed with stone fences. We descended into the valley of Passa dois on the south and went into camp. Numerous poles set upright in the ground showed that here the pack-trains halt for the night.

August 22nd.— There was a heavy frost last night. Between one and two kilometers south of camp red sandstones crop out with a northeast dip. Reaching the Rio Correntes at the noon halt, the route continued on trap to the camp for night on a small stream, the Rio das Pedras, near a farm house where were pigs and cattle in fields enclosed with rail fences.

The surface of the basalt traversed in this day's journey varied much in the degree of decomposition. For long distances there was good hard rock with a thin brownish crust of weathered products. Between these stretches along the road the rock was weathered down

to a deep brown earthy mass, and in small patches I saw reddish, and in one place, greenish clay. Bales of spherical separation appeared here and there and often the road led the mules between large angular blocks which bestrewed the hard trappean surface. The contrast between this thin coat of weathered trap and the deep beds of decomposition forming the *terra roxa* in São Paulo is very striking.

The Brazilian pine, Araucaria, occurred in small patches here and there and many young plants pointed to favorable conditions of growth for the species. An occasional Maté tree appeared along the trail, evidently due to the droppings from some passing caravan. From this high plateau there was a good view of a high trap range of tabular outline in the distant northwest, the prolongation of the Serra do Espigão extending towards Porto da União. The wooded surface of the range concealed all the rocks, but the triple terraces of the mass presumably signify a three-fold division of the trap sheets of which it is composed. Between our position at Corisco and this tabular mountain there lay an extended lower surface, the deeply dissected basin of the Rio Correntes.

Along the mule path, we passed several small grassy pools, occupying depressions partly enclosed in the trap. In at least one instance a pool lay on the upper side of the road and the water was held in by a barrier of mud and gravel accumulated in the road by wash from the descending grade on either side to the sag by which the drainage normally overflowed. The surrounding gramineous plants displayed the brown color of winter. The fine green grass of one of the pools had attracted to it a domestic horse which stood up to his knees feeding, evidence that the bottom was floored with probably the same stiff residual clay which later I saw in an excavation in one of these basins. On this monotonous succession of trap uplands of nearly uniform structure the trivial relations of the life which found a place upon them became matters of more than passing interest. On the muddy bottom of the rivulet which flowed past the evening camp I found a small fresh-water mussel resembling Unio crawling along with the open edges of the valve down so as to leave a deep narrow groove in the mud. The trail was sinuous and ended in a burrow where the mollusc pushed under a cover of mud. I should have assumed, had I not seen this animal at work, that the trail, as have been so many found in the fossil state, was to be ascribed to some gasteropod.

August 23rd.— The morning broke cloudy with rain threatening, for in this latitude on the trap plateau the distinction between a dry

winter season and a rainy summer is not so clearly recognizable as it is farther north in São Paulo. On proceeding some three kilometers through a forest of Araucaria and tree-ferns we heard a loud reverberating roar in the tall woods, a noise which my Brazilian companions announced to be that of an onza — the jaguar. With drawn revolvers they started at once into the woods in the direction of the unusual caterwauling sound, which certainly seemed to come from a large and powerful cat. From my post with the pack-train I heard their shots and presently the crash of a body falling through the trees. They had shot and killed a large howling monkey or alouatte (Mycetes), a red-furred specimen measuring about four feet from the nose to the outstretched end of the long prehensile tail. Our experience with this well-known monkey recalls the Italian proverb: —

La sera lione,
La mattine babbione.

Travellers in Brazil speak of the nocturnal howls of these monkeys but we heard their cries but twice and then only in the early forenoon.

We were soon led by a well-beaten track to make a detour from our proper route through the forest. This led us to an isolated cattle and mule ranch, whence we were directed to the main road to Corytibanos.

Our path lay through a more or less open growth of Araucaria broken in a valley by numerous stumpy palms, known as Butia. Cattle grazed on several open valley floors. On the open interstream areas we passed many of the small pools or lakelets and in one of them with the brilliant green grass before mentioned lay a dead horse whose struggles were evident from the disposition of the vegetation near his feet. I note this as an instance of how large herbivorous mammals may be tempted into swamps and under favorable geological conditions become fossilized. The animal in this instance had not become mired but probably had fallen ill from the unwonted diet. About an hour after noon we regained the thoroughfare near a cluster of houses with a monjolo or farinha mill, where we halted and cooked breakfast, on the bank of the Rio das Pedras. The basalt traversed this morning displayed many cavities lined with zeolites, fragments of these minerals glistening in the mule path every few yards. The same dull dark brown hue of the thin trappean soil appeared as farther north but I noted in one section where we descended to a stream channel a reddish rusty zone of decayed rock underlying the superficial brown coat of rock which was here about one meter thick.

The day came off clear and fairly warm, giving from one or two of the trap elevations distant views to the north and south of level sky-lines broken only by an occasional remnant of a still higher basalt sheet in the series over which we were travelling. The surface past over this morning was one of rather immature relief with no deep, steep-sided gullies or ravines. Numerous small streams showed short falls over trap ledges and rapids of no great length, manifestations of streams actively at work and far from being well graded. While we were halted on the Rio das Pedras a troup of forty mules came along bound southward. After searching in the nests of quartz which here beset the decomposed trap for other minerals, we set out and went into camp for the night on a small rivulet (Rio Ponte alto) at the base of a steep trap slope surrounded by the araucarian forest.

August 24th.— A puma came into camp in the night at about 1 o'clock and drove our dog into the tent. Alfredo fired twice at the glowing eyes of the animal but missed him. This is the sole instance in which on this expedition we were disturbed by any large nocturnal cat. During the day we saw nothing of the mammalian fauna of the forest. The tapir must be abundant in the deep recesses of the woods along the streams. We saw hanging on the wall of the store the skin of one which had been shot at the foot of the Serra do Espigão. After a ride of an hour and a half from camp we forded the river Marombas whose valley floor with a floodplain of some width lies fully 300 feet below the surrounding trap plateau. There is a small settlement of houses here in the garden of one of which I noted a palm tree and a large prickly pear cactus (Opuntia) about ten feet high. The road from this point onward crosses a succession of trap ridges and valleys, with a relief varying from 200 to 300 feet, as far as the broad elevation of cleared ground on which stands the pink and white village of Corytibanos. Here we halted for breakfast by a spring on the outskirts of the place and having rested on the warm dry grass and procured an additional supply of provisions including some bread and butter, proceeded southward along a mule path with bridges over small streams to a camp for the night. On the way we encountered in the south bank of a stream valley about 100 feet in thickness of red beds in a clayey state overlain by trap. Quartz in radiating nodules abounded in the trap traversed today, but little of geological interest could be noted in the monotonous ride over the basalt surface other than the minor variations of the topographic relief. Araucaria remained the dominant forest tree, while tree-ferns and bamboo could be seen near or along the water courses. Beside our camp, in the low

ground a few kilometers south of Corytibanos, frogs abounded in small grassy swamps or lakelets. One frog had a weak peep, another a rattling croak, and one a cry like that of a baby. The great number of these small lakelets on the trap plateau with standing sweet water even in the dry season of the year is evidence that the rock crevices are well supplied with water. The occasional rains which we encountered and the impervious nature of the deeper rock together with the residual clays which form the bottoms of depressions unite to keep much water in sight at the surface. Yet there is a great variation in the amount of permanent moisture present in the soil in the several habitats of plants, the quantity increasing from the hills towards the narrow valley floors as is exemplified in the distribution of the tree-ferns and the bamboos. We saw grass or forest fires yesterday and today in distant broad valleys.

Another puma was reported in sight by the men just as we retired. The first snake which I have so far seen in Brazil, a small bright graceful green snake, was encountered on one of the little bridges south of Corytibanos. Araucaria continues to be the dominant forest tree. With it and rivalling it in size is the scraggly imbuia whose bole attains a diameter of 3 feet or about a meter. What impressed me most concerning the trees of south Brazil was the small ovate leaves with entire margins which so many of them possess. The broad leaved oaks, maples, tulip-trees and other forms familiar to the North American as existing species with precursors occurring fossil as far back as the Cretaceous are here wanting. So far as leaf evolution goes these simple outlines recall the forms which are so characteristic of primitive types in all organisms.

On the north bank of the small stream on which we camped this night there was exposed a bed of red shale traversed by small vertical faults with downthrow in each case on the west. This stream, the Lageado penteado, is a branch of the Rio Canoas. The name Lageado applied to streams like that of Lages given to the town to which we were bound has reference to the slabs of sandstones which abound in this region and "pave" as it were the beds of the small streams.

The Canoas river has shifted its course in the degradation of the region down the dip of the formations so as to hug the southern edge of the basalt.

I saw no fossils in the red shales but found some concentric conchoidal fractures or joints.

August 26th.— Light showers during the night. Ant-hills and

red soils are not so common on this Triassic area as on the north in Paraná and São Paulo. The basalt has disappeared from a large tract about Lages without leaving any noticeable trace.

At 9:25 A.M. we came to the Rio Canoas which is here a broad deep stream over which our pack-train was ferried on a platform supported by four dug-out canoes and held to its course by a wire cable. On the upland we passed the hamlet of Canoas with oxen ploughing. Shortly before noon we descended a steep slope to a stream crossing with red shales dipping north in the bank. Farther on the mule path traverses a dike about seventy-five feet wide cutting the sandstones. This dike is heavily charged with fragments of several rocks and minerals evidently brought up from below. About a mile farther south a narrow dike about one foot wide occurs along the trail near a small stream. About a mile farther south there is a short low ridge on the east of the road with small conical spurs and buttresses of inclined beds on its north side. On approaching this point on the road with a slight rain falling thousands of winged ants flew over the campo up to fifteen feet in the air and for some reason chose to collect behind my head in great numbers. On catching up with the party I found the tent pitched in a clump of bushes at the western end of the ridge just as a steady rain set in for the night.

The small lakelets so characteristic of the trap surface also occur in the sedimentaries south of the escarpment. Here the depressions appear to mark the site of springs. From the dike southward the dip is southerly and probably S. W. There is a small anticlinal fold near this camp with axis NNW–SSE.

August 27th.— It rained nearly all night and until 7 A. M. We rode southward across the bleak campo to a descent over sandstone beds which brought us, after a journey of fourteen days from Ponta Grossa, into a broad irregular valley in which Lages lies.

August 28th.— The light brown Triassic sandstone under a red shale bed north of Lages is quarried for building stone and flagstones. No fossils other than wandering trails were to be seen in the sandstone. Certain greenish shale beds pass laterally and obliquely to the stratification into red beds, and well-defined green-walled joints in the red beds show that the green color is locally a post-depositional alteration of the deposits. In the afternoon we returned northward, to the locality of the dike bearing inclusions, for a more detailed study of that rock.

Ant-hills about fifteen inches high bestrewed the surface of the Triassic sedimentary tract. As usual most of the hills had been

broken into by some burrowing animal and many colonies were abandoned. This cycle of change must several times have worked over the surface materials of the campos of Brazil and facilitated the work of erosion by winds and rain.

When it is recalled that a large insectivorous fauna including the anteaters, Myrmecophagidae (Vermilinguia), inhabit the ant-occupied surface of Brazil and that this group is specialized with reference to the ants and that traces of this organic adaptation go back to Pliocene times, it is evident that ants and anteaters have exercised an important function in the geologic processes which have worked together in the evolution of the surface deposits of Brazil. Fossil ants are numerous in the Oligocene beds of Florissant in Colorado (Scudder) and anteaters appear in the Miocene Santa Cruz formation of South America, dates which are as far back if not earlier than the beginnings of the present surface deposits of the Brazilian highlands.

August 29th.— The road northward from the camp at the dike passed over alternating beds of red shale and yellowish to reddish sandstones, dipping gently to the northwest towards the southern margin of the trap sheets, whose escarpment, as far as it could be seen, extended in a northeast-southwest direction roughly parallel to the strike of the underlying sediments. From the top of one of the monoclinal ridges between the Rio Ponte alto and the Rio Canoas, this escarpment could be traced to the eastern horizon where a conical outlier stood out in clear relief as a monument to the erosion of the trap cover which formerly extended over the Lages area.

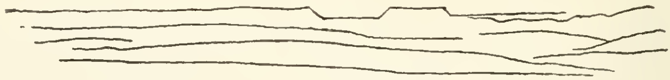

Fig. 4.— Field sketch of the trap plateau northwest from Rio Marombas in Santa Catharina.

The monoclinal structure of the sediments results in a series of ridges with steeper faces on the southeast and longer gentle slopes to the northwest. At about twelve kilometers from camp we crossed the Canoas River, and continued northward to the north bank of the Rio Ponte alto where we camped by a covered bridge. The stream at this point flows in a channel about twenty feet deep over sandstones with an active drainage.

August 30th.— After a march of an hour and fifty minutes from camp we passed over sandstones striking northwest and dipping about 15 degrees to the northeast. About forty-five minutes later we

surmounted the dissected trap plateau at an elevation of some 700 feet above the valley of the Rio Ponte alto. The broad valley of the Rio Cachoeiras which next succeeds exposes a bed of sandstone in its banks below which lies a trap sheet over which in turn it flows. About ten miles north of the river we camped for the night near a frog pond between two of the mule bridges which mark the approach to Corytibanos.

August 31st.— An hour's ride from camp brought our cavalcade again to Corytibanos, at which point we took the road northwest towards São João *en route* to Porta da União on the Iguassú. For several miles along this route we traversed campos with a scattered growth of the the araucarian pine and then of the Butia palm. One deeply weathered trappean hill bore numerous lakelets or lagoas bordered by tall tufts of grass. Blackened heads of trap rock cropped out over the surface of the inosculating ridges which separate these solution-basins. At noon we halted beside a small stream whose milky waters were without apparent cause since it had not rained. On resuming our march we shortly heard the roar of falls in the course of the Rio Marombas on the left in the forest where the river tumbles over the bedded traps. The river was crossed on a balsa or ferry, a sort of raft supported by four or five wooden canoes. (Plate **17**). A forest fire was burning on the east bank of the river. After traversing two deep valleys and a broad hill of dry campo we camped on another small milky stream in a cattle country. The milkiness of these small streams was possibly due to cattle wading in them. The day was warm, and beetles, butterflies, and dragon-flies were out fluttering over the muddy flats of a stream at noon.

September 1st.— About an hour and a half after leaving camp this morning, we came to the Rio Correntes which was forded on a trap bottom. After proceeding for an equal length of time we crossed another broad shallow stream with rapids, the Rio dos Patos, also on trap. We followed up the right bank of this river in a northwest direction until nearly noon when we came to a *coboclo* hut in the forest, where a woman gave us directions. Our halt for breakfast at the noon hour was beside another small sluggish milky stream. Several of the solution-basin lakelets were passed during the forenoon. As the trail was not distinctly marked from the paths leading from one hut to another in this forested region, much of the afternoon was spent in seeking directions. A large forest fire at one time was raging to the west of our position. Fires in the standing clumps of dry dead bamboo burn with great rapidity. At length we entered

a burnt over tract of Butia palms, where beside one of the milky streams we encamped for the night. My mule had given out during the afternoon and was towed into camp tied to the tail of a sound animal. In the forest along the trail I observed a small wild tobacco plant from four to five inches high, which our head camarada termed "fumo dos Bugres." A pair of papagaios flew over the camp at sunset and a few mosquitoes buzzed about our fire of araucarian knots.

The Brazilian pine (*Araucaria brasiliana*), when young, resembles in its branching habit the other members of the Coniferae; but it scarcely attains full height before its branches become crowded towards the top by the dropping off of the low ones. An old tree thus presents a clean bole with usually one but sometimes two great whirls of branches at or near the top and recurved upwards. Upon the fall of a dead tree frequently as much as ten feet of the upper extremity of the prostrate trunk is a mass of highly resinous knots which remain undecayed for years after the surrounding wood has disappeared. In the wettest weather a fire of these knots can be quickly made. Along the line of railway in southern Paraná the knots are used for fuel on the locomotives, and bins of these combustible, inflammable stores of the araucarian forest are frequently seen at the railway stations. The young trees when not over four to six feet high present an appearance very unlike the adult form with its smooth bole and palm-like apical whirl of branches with leaves growing in large clusters at the ends of the branches. The young tree is thoroughly covered with broad pine leaves resembling small Cordaites. On the branches these leaves point outward and upward, but those on the bole which are still larger bend sharply downward at the point of attachment and present sharp needle-like points to stay the progress of any small climbing mammal which would find equal difficulty in reaching the main stem of the tree by descending one of the branches. This apparent adaptation of the foliage to protection from arborescent animals in the young stage of the plant is a devise the use of which I did not observe, for on account of the nocturnal habits of most of the animals of the Brazilian forest and the noise made by the approach of our troop of mules we saw during the day no wild mammals whatever.

September 2nd.— For over two hours after leaving last night's camp, our route lay through the forest on the south slope of the Serra do Espigão. About 11 A. M. we emerged on a more travelled trail along which we passed several huts. Late in the afternoon the sick mule lay down and we were forced to abandon the animal, as our

slender stock of provisions obliged us always to make rapid transits of the long stretches between settlements. We camped on the head-waters of the Rio dos Patos, the bed of which abounds in agate pebbles derived from the trap.

September 3rd.— The mule road ascended rapidly from camp to elevations by aneroid of 4,000 feet on the crown of the northwestern arm of the Serra where there is a small settlement and a store. Small streams continued turbid. The interstream areas were weathered into deep pits with numerous bogs.

September 4th.— The march to the northwestward today lay at a high level on the northeast side of the crest of the Serra, a rolling country partly open campo and partly occupied by pine. Inhabitants became more frequent and pack-trains indicated the proximity of the terminus of the railway. At half-past two we heard the whistle of a locomotive and at 5 P. M. came out upon the line of the railway in construction from Porta da União southward over the trap plateau to the Rio Peixe. At 9 o'clock at night we found our way into São João, from which place on the following day we returned by train to Ponta Grossa leaving the pack-train to come along at its own gait.

September 15th.— With the view of studying more in detail the tillite beds on the banks of the Rio Jaguaricatu in northeastern Paraná, Dr. Oliveira and myself with a small camp outfit and one camarada went from Ponta Grossa to Sengéns Station on the newly constructed railroad. While absent from our camp on the 16th, our tent and most of the contents were destroyed by a fire. Fortunately none of my instruments or notes were lost. Through the courtesy of the railway officials we slept in a railway storehouse that night and the following day returned to Ponta Grossa.

September 19th.— In company with Dr. Euzebio Oliveira I returned to Rio Negro with the intention of exploring the tillite beds along the road between that town and São Bento. It was on this occasion that Dr. Oliveira found a bed of fossiliferous marine shales between boulder-beds on the south side of the Rio Negro. About two legoas above Rio Negro there is a water-fall where the Ribeira das Rutes falls over a hard bed of tillite.

From Rio Negro I returned to Curityba *en route* to Paranagua, whence by steamer I reached Rio de Janeiro. The delay in waiting for the steamer was utilized at Curityba and at Paranagua in examination of the superficial deposits and studying the topography the results of which studies are embodied in the account of the geomorphology of this part of Brazil.

From Rio de Janeiro, again through the intermediation of Dr. Derby, I set out on October 12th for the planalto of São Paulo to examine the tillite beds on the railway line between Itaicy and Piracicaba. Dr. Cardoso, chief of the São Paulo Geographical and Geological Commission detailed Dr. Pacheco of that bureau to accompany me. The excursion was made with a railway automobile, over the part of the line traversing the sediments. This afforded every opportunity for a rapid reconnaissance. On returning to Rio de Janeiro, I sailed from that port on October 24th bound to Laguna for the purpose of examining the Permian section of the Tuberão Valley. Dr. Euzebio Oliveira joined me at Paranagua. On this and the return voyage the necessary delays in waiting for the small coasting steamers gave opportunity of making observations upon shore-line changes and the general features of the Serra do Mar at São Francisco, Itajahy, Florianopolis, and Laguna.

While waiting for the steamer at Laguna a study was made of a sambaqui or shell-mound forming a small terrace on the flank of the granite hill at the south end of the town. The top of this deposit is about 100 feet above sea-level and has been dug into as a local source of lime. The deposit is composed principally of a small lamellibranch, in parts of the mass somewhat cemented together. In the upper part of the heap I found a stone-axe, fragments of a fine-grained rock evidently used for opening shells, fish-bones, mammalian bones, and part of a human skull, as well as portions of a large sea-urchin, all indicating by their leeched condition considerable antiquity. At a lower level a large Ostrea was abundant. The deposit has a rough stratified structure but nothing like that induced by deposition beneath moving and assorting currents of water. Neither in the topography nor in the structure were there characters seeming to demand other than surface accumulation for the origin of this shell-heap. The dead shells of a recent large snail, Bulimus, were rather abundant on the surface of the kitchen-midden, and the old shells were sliding down to the present beach. Professor Dixon has kindly written a note on the collections I made at Laguno, (p. 132).

Voyage from Rio de Janeiro to Talcahuana. November 25th, 1908. The journey from Brazil through the straits of Magellan to southern Chile was begun today by sea on the steamship *Oravia* of the Pacific Navigation Company, with stops at Monte Video, Punta Arenas, and Coronel.

November 29th.— At Monte Video. Two partly dismasted barks lay at anchor in the harbor, having fallen back to this port for repairs.

after an encounter with ice off Cape Horn. Captain Wm. B. Oakley of the *Oravia* informed me that after the Valparaiso earthquake of 1906 there had been an unusual amount of ice in the sea about the southern end of South America, the ice having been dislodged from glaciers by the earthquake, so it was believed. This report agrees with the effects reported by the late Prof. R. S. Tarr arising from the Alaskan earthquake of 1899, which caused much disturbance of the glaciers on the Alaskan coast and warrants the belief that at least local earthquakes may greatly accelerate the flow of glaciers.

December 4th.— We entered the straits of Magellan during the night. To the voyageur entering the straits from the east the high barren plains on the north and the treeless low-lying plain of eastern Tierra del Fuego on the south alike recall the plains of glacial Cape Cod veneered with glacial drift. Between Elizabeth Island and Punta Arenas there are some irregular terraces of varying height, appearing more like glacial contemporaneous terraces than the horizontally levelled benches cut by waves. Back of the town of Punta Arenas there is a deep gully at the mouth of which lies a prominent deposit forming a rounded southward slanting ridge, on the seaward slope of which the town is mainly built. There is a remnant of what appears to be a stream delta north of the town, now forming a terrace. The *Pour-quoi-pas* of M. Charcot's French Antarctic expedition lay at anchor off the town.

The passage from Punta Arenas to Cape Holland was made after 4 P. M. but permitted a general view of the profile of the Andes rising above the plains of Tierra del Fuego. (Fig. 5.) It is evident

FIG. 5.— Generalized profile of the Andes on Tierra del Fuego, showing the arching up of a once baselevelled but now deeply dissected mountain mass. It is not here intended to interpret the steep western descent into the Pacific Ocean.

that here as far to the north the peaks and valleys are carved out of a theoretically smoothened surface of the deformed rocks composing the folded chain. It is conjectured that this now warped, once baselevelled, surface passes beneath the Tertiary and Pleistocene deposits of the plains of Tierra del Fuego, forming the platform on which these less ancient deposits repose. Towards the western margin of

the Andesian uplift, the dissection of the surface is more complete, and the descent to the bed of the Pacific Ocean is steep.

December 8th.— The *Oraria* put into Coronel for a supply of coal. The mines at and near Coronel are the most important on the coast of South America. The principal outcrop of coal is inland, some distance from the shore but the workings follow the coal beneath the sea. The beds in which the coal occurs are regarded as of Eocene age. (Sundt, 1908, p. 37–44). The coal is bituminous and is described as bright and clean but light. The Arauco Company has produced from its mines as much as 200,000 tons per annum. The coal is extensively used by steamers plying the west coast and in the locomotives of the Chilean railway (Alcock, 1907, p. 85).

Captain Oakley of the Pacific Steam Navigation Co. expressed the opinion that the coast at Coronel has risen in recent years. An old wreck partly buried in the beach skirting the south side of the point on the north of the anchorage, according to his observation now lies higher than when he first saw it. I note the opinion as a matter for further investigation.

While the steamer was taking in coal I went in a sailboat to Lota, a small port about four miles south of Coronel, where coal is also mined. A conglomeratic sandstone here crops out, the scattered pebbles and massive bedding of which strongly suggests the transportation of the pebbles by ice. In my hasty examination of the rock I was unable to find striated pebbles. It should be noted in this connection that Darwin (1846, p. 69) described "great boulders of granite and other neighbouring rocks, embedded in fine sedimentary layers" in Tertiary deposits along the coast of Peru. Back of Coronel there are at least three terraces in the bed rock but whether due to differential weathering or marine erosion at different levels I was unable to determine. Along this coast towards the Tumbres Peninsula there is an uplifted baselevelled surface forming a narrow bench cut back and cliffed by the sea at the present level, with subdued remnants of higher rock masses rising above the terrace as in the case of the Paps of Bio Bio. This bench must be early Pleistocene or late Tertiary in date. Narrow steep ravines crease the cliff face; but practically no stream-cut channels cross it with their mouths at sea-level. All the small vales which traverse the bench are hung up at the seaward edge by reason of the cutting back of the terrace by the sea. This bench is probably to be correlated with a well-defined bench of erosion at Corral on the south but is much higher above the sea.

We entered Concepcion Bay on December 8th, and on the 9th I went ashore at Talcahuano. I spent several days in the vicinity of Concepcion examining evidences of change of level. As the results of my observations are given in a subsequent chapter I make mention here only of some unrelated geological details.

On December 11th, while yet in bed, at about ten minutes past seven, I felt a slight quivering followed by a sharp lurch of the hotel. The wooden framework of the ceiling cracked and creaked. The daily press stated that at 7.10 a short but violent shock was felt. Again on the 13th of December while in Concepcion, the daily press reported during various hours of the night subterranean noises accompanied by a shock at 12.40 A. M., which caused some alarm. I was awakened at about 1.35 A. M. by what at the time I thought was the fall of an object in the room below; meanwhile I heard a rumbling noise sounding like that made by street cars. The destruction of Valparaiso by the earthquake of August, 1906, has made the inhabitants fearful of a repetition of such violent earthquakes, particularly at Concepcion whose ancient site at Penco on the shores of the Bay has been the seat of the most famous earthquakes in the annals of Chile. The practice of the Spanish in South America of leaving a site more than once damaged by earthquakes has much to recommend it. In the case of Old Concepcion or Penco, twice destroyed by earthquakes and inundations from the sea, the site was mainly on a marsh behind a barrier beach filling out an indentation of the coastal hills, a location, owing to the soft nature of the recent alluvial deposits, likely to be severely shaken by earthquakes. The new city of Concepcion stands on a plain of Pleistocene alluvium mantling much disturbed sandstones which here and there rise as low hills through the plain. That this city has escaped destruction so far from earthquakes is seemingly due rather to the failure of local violent shocks than to its location.

On December 13th, I visited Penco, the site of ancient Concepcion. Since Darwin's time the construction of a railway along the shore of the bay has led to the partial demolition of the old Spanish Fort, the seaward portion of the walls only remaining. (Plate **4**). Of what I presume to be this building, Lyell states: "It has, however, been ascertained that the foundation of the Castle of Penco was so low in 1835, or at so inconsiderable an elevation above the highest spring tides, as to discountenance the idea of any permanent upheaval in modern times, on the site of that ancient port; but no exact measurements or levellings appear as yet to have been made to determine this

point, which is the more worthy of investigation, because it may throw some light on an opinion often promulgated of late years, that there is a tendency in the Chilian coast, after each upheaval, to sink gradually and return towards its former position." (Lyell, Principles of geology, 11th ed., New York, 1887, **2**, p. 156). I found this view still current at Talcahuano, and it is evident from the view referred to that no marked permanent change of level has affected the ancient ruin on the beach at Penco since it was constructed.

The railway from Concepcion to Penco traverses an outcrop of coarse, waterworn conglomerates at Paradero de Santa Ana, evidently a member of the Tertiary series which underlie the plain between the Coastal Cordillera and the ridge of crystalline rocks which form the Tumbres Peninsula on the seaward side of the Bay of Concepcion. In the bank of the bay shore immediately south of Penco, coarse gravels composed of pebbles of crystalline rocks and occasionally large rounded stones crop out in the railway cut in marked unconformity upon sandstones. The change from the blue color of the gravels at the base to orange at the top of the bluff is evidently an effect of weathering now in progress. Certain portions of the pebble beds contain stones a foot or more in diameter. The deposit is mainly stratified with flattish ovoid pebbles lying in the planes of bedding. In the lower part of the exposure the paste of fine material is less obvious than in the upper portion. Lenticular beds of sand and finer gravel appear at intervals in the section, pointing to intermittent or shifting currents or streams. From its general relations and want of consolidation I supposed the deposit to be of Pleistocene date and possibly not older than the bench which at about the same elevation can be traced around the seaward face of the Tumbres district at the Paps of Bio Bio. If this correlation be correct the deposit may be of marine origin, but no fossils were seen in any part of the section.

On the exposed face of the gravel bluff loose materials were sliding down in such a manner as to afford an instructive example of the post-depositional striation of pebbles. A large rounded cobble protruding from the section (Fig. 6) was well striated on its exposed surface by pebbles sliding down over it in the wasting of the upper part of the bluff. I observed this process in action, and it showed the necessity of taking every precaution in accepting detached striated pebbles as evidence of glaciation.

On December 18 I left Concepcion for Valdivia to examine the shorelines of that district for the reason that Darwin stated that here he

found no local indications of elevation. The results of this journey are contained in my remarks on the coast of Chile. (p. 132).

December 23th.— Being due at Santiago on Christmas day I left Valdivia, journeying northward by rail through the Longitudinal Valley of Chile, with a stop at San Rosendo to make a study of the Pleistocene terrace deposits on the Rio Bio Bio. In ascending the valley of the Calle Calle through the gorge in the Coastal Cordillera, the crystalline schists were observed to have the same steep eastward dip as in the Tumbres Peninsula in the latitude of Concepcion. The rock-bench which is so pronounced a feature about the shores of Corral and the Valdivia River along the Calle Calle above Valdivia becomes suffused with gravels, presumably Pleistocene. Pebbles of nonschistose rocks abound, indicating the derivation of the materials from the Tertiary and volcanic rocks within the Longitudinal Valley.

FIG. 6.— Section showing how exposed surface of a cobblestone became striated by gravels sliding down in direction of arrow; at Penco, Chile.

From December 25th, 1908, until January 5th, 1909, I remained in Santiago in attendance on the sessions of the First Pan-American Scientific Congress. I have published a brief note on the geological papers read at this meeting. (Woodworth, 1909).

Under the guidance of Dr. Phillipi, a visit was made to the Museum of natural history and to the Museum of the mining society. Among the collections of this Society I was shown several remarkably intricate examples of stones carved by the sand-blast. These were gathered on the surface of the desert of Atacama by Mr. Carlos Sundt. In some cases large holes had been eaten through irregularly carved fragments of rocks by this insidious process. Through the courtesy of Major Montessus de Ballore I was also permitted to examine the Seismological Observatory then in process of installation in the hill of Santa Lucia in Santiago. This is the principal station of the seismological service of Chile. From Santiago I proceeded to Valparaiso for embarkation on a steamer bound for Panama.

The Valparaiso Earthquake of August 16, 1906. While waiting in Valparaiso for the sailing of the steamship *Limari,* a day was devoted to a casual examination of the effects then visible of the disastrous earthquake of August 16, 1906. As has been so often observed in the downthrow of maritime cities by earthquakes, the

damage was most severe along the water-front where the alluvial deposit and made-ground imposed the thickest layer of loose unconsolidated material upon the bed rock. In this zone many buildings were completely levelled. Nearer the base of the cliff which partly separates the upper from the lower portion of the city, buildings stood with their walls cracked and cornices broken away but frequently otherwise safe for habitation. Upon the sloping ground above the line of cliffs where a superficial layer of weathered rock on the inclined surface had slipped down carrying buildings with it, and in the cemetery where similar conditions existed, the destruction was most pronounced. The reconstruction of the business houses along the incoherent ground of the water-front insures a recurrence of the tale of destruction when in the future the seismic movement affects in this vicinity the line of displacement which skirts the coast of Chile. From the studies of Dr. H. Steffen in the case of this earthquake the disturbance appears to have had its origin off Coquimbo, a sea-port 198 marine miles north of Valparaiso.

I was impressed with the fact that in a large number of the houses that were not completely destroyed the damage was at a maximum in the peripheral parts of the buildings; that though one or more of the outer walls were demolished or thrown outward, the internal walls and the inner angles of the floors were left standing in place unencumbered by fallen wreckage in such a manner that persons unable to leave these buildings would have escaped with their lives had they sought refuge during the height of the shocks in the internal corners of the rooms. I had occasion later to note instances of the same sort amid the ruins of Kingston, Jamaica, produced by the earthquake of January 14, 1907. It would seem advisable from this observation that houses in earthquake countries should be constructed with one or more sets of rectangularly intersecting, internal walls well united of materials whose period and amplitude of vibration as a mass is identical so that one end of the building will vibrate as nearly as possible in unison with the other. From the lack of this synchroneity and equality of lateral swaying the outer walls will probably be thrown off or toppled down but the central structure of buildings properly balanced, as numerous examples have shown, often stands and by a slight special construction adapted to the purpose, the internal angles of such intersecting walls might in many cases prove places of refuge and security.

This Chilean earthquake, coming at a time when the people of the United States were preoccupied with the calamities of the similar

great disaster which had but four months previous led to the destruction of San Francisco, has received such scant attention in North American scientific journals that the following notes taken largely from local accounts and the paper of Dr. H. Steffen of the University at Santiago are deemed worthy of record.

In Valparaiso the immediate loss of life was estimated at 3,000 persons and the wounded at 20,000, some of whom subsequently died in consequence of their injuries. Several hundreds of lives were lost in surrounding towns and villages. (Rozas y Cruzat, 1906.)

Owing to the lack of seismographs in Chile in 1906, the exact time of the earthquake is a matter of some uncertainty. At Santiago where there is an astronomical observatory the first sensible shock appears to have taken place 7h. 58m. 36s. P. M., August 16th, local time. Taking the longitude of Santiago as 4h. 42m. 46.4s. west from Greenwich, the initial shock was felt there at 0h. 41m. 22s. Greenwich mean time, midnight to midnight, August 17th. At Valparaiso whose time is 3m. 50s. later, the first shock is placed at 7h. 55m and at 7h. 56s. by several different time-keepers. The mean of the times at Valparaiso, 7h. 55m. 30s. makes the apparent time of the first shock at Valparaiso 44 secs. earlier than that at Santiago. The earthquake from various studies appears to have originated in a fault plane off Coquimbo about 228 miles north of Valparaiso. The seismographic indications as to the time of origin point to 0h. 40 m. as the probable moment of the primal great shock.

From the varied estimates of observers, it appears that in the central tract along the coast extending north and south of Valparaiso between the parallels of 28° and 39° S. L. there were two series of shocks separated by an interval of relative quiet. The first strong shock of exceptional duration, lasted from four to five min., while the second equal to or perhaps stronger than the first one had a duration of 1 min. or less. Outside of the epicentral region but one continuous series of shocks seems to have been noticed. (Steffen, 1907, p. 23). A vertical movement was distinctly recognized at isolated points between 38° and 36° S. L. with greater distinctness and precision on the north as far as the river Mante. Most observers judged the primal movement to be upward. Dr. Steffen obtained testimony to the effect that heavy objects in Illapel, Santiago, Talca, etc., within the central tract were thrown upward to a certain height above the base on which they stood, contradicting as he notes the statement of Dutton (1904, p. 148) that there never has been observed an acceleration sufficient to overcome the force of gravity. It may

be noted also that in the Indian earthquake of 1895 (Oldham, 1899), many large boulders were inverted on their sites in a manner demanding apparently their projection free from the base on which they rested.

The most important data gathered by Dr. Steffen has a definite bearing upon the controversy raised by the distinguished Austrian geologist, Professor Edward Suess, over the question of the uplift of the coast of South America accompanying earthquakes, a thesis set forth by Darwin and Fitzroy. Dr. Steffen was aware of the importance of critical observations made at once upon evidences of change of level of land and sea along the disturbed coast. From the information obtained he came to the conclusion that there can scarcely be any doubt as to an elevation of the coast from the mouth of Rio Mataquito to that of the Choapa along a segment of the sea-border corresponding to the area of maximun perturbation in which the seismic intensity rose to the degrees of VII and X in Mercalli's scale. This movement appears to have been greater on the north than on the south. The measurements most worthy of confidence in Dr. Steffen's opinion are 40 cm. at Llico, south of Valparaiso in about 34° 40′ S. L. and 70 to 80 cm. at Zapillar, north of that city in about 32° 25′ S. L. Señor Lorenzo Sundt, an experienced geological observer whom I met in Santiago, stated that in the bay of Valparaiso some 200 meters west of the pier of the Matodero at Portales, there was to be seen upon the rocks after the earthquake a white band composed of a small species of barnacle and of Algae of the Corallinacea forming a natural mark which at time of low tide was left uncovered for two feet above low-water mark, although before the earthquake it was not visible. Likewise a local officer of Portales who had observed the coast for eighteen years noticed after the earthquake that a rock, which he had not seen before appeared above the surface of the lowest tides. These stations which are composed of the solid rock are free from the doubts which affect the altered position of loose materials. The probable correctness of the contention of Darwin and Fitzroy that at times of great earthquakes on the coast of Chile there is an upward movement of the land seems now to be established; but whether this uplift is permanent is doubtful, since as in the celebrated case of Concepcion, I was informed when in that vicinity that it was the opinion of the naval officers stationed at Talcahuano that a slow subsidence is now in progress. As for the uplift of faulted blocks in relation to sea-level it is now well established and nowhere more pronouncedly than in Alaska by Tarr in the case of the earthquake of 1899 in which an

elevation exceeding forty-two feet was ascertained by indubitable evidence. But this case arose in a folded mountain-chain of recent development where uplift is not denied by Suess. The Coastal Cordillera of Chile is composed of an elongated horst lying outside of the folded chain of the Andes and the evidence of uplifts at the time of the Valparaiso earthquake of 1906 is therefore of especial interest in confirming the conclusion of Darwin and Fitzroy that an elevation of the coast may take place concomitant with an earthquake on this coast, though it does not prove that the coast has been permanently elevated by successive stages at long intervals in this manner.

From the information collected and published by Dr. Steffen, we also learn that no noticeable seaquake wave or tsunami was set up in that part of the coast which was the seat of the maximum seismic activity and change of level. At Constitucion and particularly in the bay of Talcahuano unusual movements of the sea, however, appear to have taken place. At Tomé on the eastern shore of this large shallow harbor at a time differently stated as a quarter of an hour and as an hour after the earthquake, the sea retired for about fifty meters, returning quietly to its place. This movement was repeated three or four times, the last two incursions being the greatest, covering a space of seventy meters. At Penco, the site of Old Concepcion, made famous by the number of times it has been devasted by earthquakes and sudden irruptions of the sea, similar phenomena took place. A wave rose to the level of the railway (Plate **4**) along the beach and passed through the bridges and drains to the low ground behind, causing the inhabitants in their alarm to begin to take refuge in the neighboring hills; but the sea returned, so it is stated, to its normal level in less than ten minutes. (Steffen, 1907, p. 66–67).

The Valparaiso earthquake followed immediately upon a heavy earthquake on the submarine border of the Aleutian Island platform in 50 N. L. and somewhere between 175° and 180° of longitude E. from Greenwich according seismometric determinations.[1] The mean of the determinations of the time at origin of this shock by Zoeppritz, 0h. 10m. 47s., and by the observatories at Florence, 0h. 10m. 35s., Laibach, 0h. 11m. 19s., and Tokyo, oh. 11m. 16s., is 0h. 10m. 59s.

[1] Zoeppritz places the origin within 100 kilometers of 180 of Longitude from Gr. and the time as 0h. 10m. 47s. ± 20s. See E. Rudolph und E. Tams Seismogramme der nordpazifischen und sudamerikanischen erdbebens am 16 August 1906, Strassburg i. E. 1907. Professor Omori gives the origin at 175 +° E. L. and the time as 0h. 11m. 44s. G. M. T., midnight to midnight.

which may be taken as 0h. 11m. or about 29m. 10s. previous to the calculated time of the Valparaiso shock at origin.[1]

According to Benndorf the secondary preliminary or transverse group of seismic waves arrive at distances of 14,000 kms. after an interval of 30m.; according to Rizzo's later work, we may expect them to arrive as early as 29m. 30s. after the primal shock, or after a mean interval of 29m. 45s. ± 15s. It thus seems highly probable that the Valparaiso shock was set off by the passage of the vibrations emanating from an earthquake in the Aleutian Islands.[2]

Voyage from Valparaiso to Panama, and thence to New York. On the 7th of January 1909, I sailed from Valparaiso by the Chilean steamship *Limari* for Panama, with stops at various ports on the intermediate coast. Along this coast as far north as the island of San Gallan near Callao, from time to time one sees from the deck of a passing vessel sea-caves somewhat above the present level of the sea, indicating a modern uplift in relation to sea-level. Above these recent indications of a change of level the embayments of the coast are terraced as at Coquimbo and Ilo to a height of a few hundred feet. Usually above the highest terrace which is somewhat more eroded and creased by ravines than those successively lower, there rises a dissected slope to the edge of the lofty plateau. That these terraces facing the sea indicate changes of level one can hardly doubt. Were they due to differential weathering the upper ones would be as sharply defined as the lower terraces. In this respect the coast is in sharp contrast to much of the region south of Valparaiso. We reached Panama January 26, where our fellow-passenger Colonel Gorgas of the Isthmian Canal Commission showed us many courtesies. On January 27 I sailed by the Royal Mail Steamship *Nile* for New York with a stop at Kingston, Jamaica. This enabled me to spend a day in the examination of the destructive work of the earthquake of January 14, 1907, the effects of which were visible on every hand in the unfortunate city. The *Nile* arrived at New York February 4th, 1909.

[1] The initial Valparaiso shock according to the results obtained at Laibach took place at 0h. 40m. 5s. Cf. Galdino Negri. Velocidad de propagacion de las Ondas Sismicas. Observatorio astronomica de la Universidad nacional de la Plata. Memoria presentada al IV Congreso cientifico internacional americano celebrado en Buenos Aires del 10 al 25 de Julio de 1910. La Plata, 1911. p. 100.

[2] See in this connection, Quelques constantes sismiques trouvées par les macrosismes. Nota d'Emilio Oddone da Roma. Strassburg, Bureau Central, 1907.

IV. OUTLINE OF THE GEOLOGY OF SOUTH BRAZIL.

For the understanding of the relations of the Permian glacial deposits of south Brazil it is proper to give a résumé of the geological structure of the country. Passing over the pioneer work of Lieut. Colonel Wilhelm L. von Eschwege, whose writings are lithological rather than geological, the main outlines of this structure are to be found in the publications of Dr. Orville A. Derby and his associates, Dr. J. C. Branner's résumé in his Geologia elementar, and in Dr. I. C. White's Report on the coal area. In this résumé the observations of the writer have been allowed to a limited extent to enter into the interpretation of certain features of the region.

The formations which enter into the structure of this part of Brazil may be grouped in the following terranes: — 1. The Pre-Devonian or igneous and metamorphic belt of the coast including the Serra do Mar region, frequently classed as Archean. 2. The Devonian including the sandstone cuesta of the Serra das Furnas and the overlying fossiliferous shales of Ponta Grossa in the state of Paraná. 3. The Permian beds, including conglomerates, tillite beds, as well as sandstones and shales, the latter coal-bearing in the south. 4. The Triassic sandstones and trap sheets; the latter making the escarpment known as the Serra Geral and its topographical equivalents elsewhere. 5. The Tertiary fresh-water deposits of the upland and possibly along the coast. 6. The Recent deposits along the coastal border now slightly elevated.

The Pre-Devonian Terrane.— The Pre-Devonian belt is here so-called because it comprises a complex of igneous and metamorphosed sedimentary rocks unconformably overlain by the westward dipping Devonian sandstones and shales of the upland, as yet the oldest known fossiliferous group in the region. The use of the term Archean or Pre-Cambrian for this complex seems at present inadvisable because of the possibility that certain of the metamorphosed clastic members of the series may be of Lower Silurian (Ordovician) or Cambrian age analogous in their structural relations to those of these ages in the metamorphic belt of the Piedmont terrane of the Atlantic slope of North America.

In the latitude of Rio de Janeiro this belt of complex rocks includes the elevations known as the Serra do Mar and an inner line of mountainous relief known as the Serra da Mantiqueira. Gneiss of undetermined origin appears to be the most ancient member of the region

and may be fairly presumed to be of Pre-Cambrian age. In the coastal border gneissoid granites with well-developed augen-structure abound. This rock is nowhere better shown than about Rio de Janeiro, as in the Pão de Assucar at the entrance to the harbor. Apparently of later date than the granite-gneisses are intrusions of phonolite and tinguaite which occur in the form of stocks, while more basic dikes are not wanting.

In eastern São Paulo there is an evidently infolded belt of slates and limestone, seemingly the newest member of the metamorphosed series. The distribution of this formation has not been shown on geological maps. In southeastern Santa Catharina the belt between the Permian border and the coast appears to be entirely granitic, though north of this district quartz-schists are involved in the complex as in the vicinity of Itajahy.

North and south of the Permian-Triassic basin of south Brazil these Pre-Devonian rocks have a vast extension, stretching far into the interior in the state of Minas Geraes and forming the greater part of Uruguay. In the region south of Rio de Janeiro it is evident from the relations of this series to the overlying Devonian beds that one or more periods of deposition, mountaining-building, and igneous intrusion preceded the deep erosion of the deformed mass as the prelude to the incursion of the Devonian sea. The once eastward extension of this deformed and eroded Pre-Devonian terrane into what is now the basin of the Atlantic Ocean has no assignable limits. The basal beds of the Devonian rest on a westward dipping now slightly warped surface of these older rocks in a manner to show that the sea crept in over a region of little or no relief but how far this peneplaned surface extended to the eastward there are no definite facts to show.

The Devonian Terrane.— The Devonian of south Brazil occupies a narrow belt of outcrop along the eastern margin of the Permian area, disappearing on the north in São Paulo and on the south in Paraná. As strata of Devonian age reappear far to the northwest at Cuyubá in Matto Grosso, the Devonian is thought to extend beneath the Permian and Trias over a vast area. It is agreed that the Devonian of South Brazil includes at its base the thick, light-colored sandstones which form the Serrinha and the Serra das Furnas. This formation is overlain by fossiliferous shales of Mid-Devonian age. The Devonian shales are intruded by numerous dikes and sills of diabase whose outcrops may be seen in the vicinity of Ponta Grossa. Their date of intrusion is probably Triassic. The absence of the Devonian

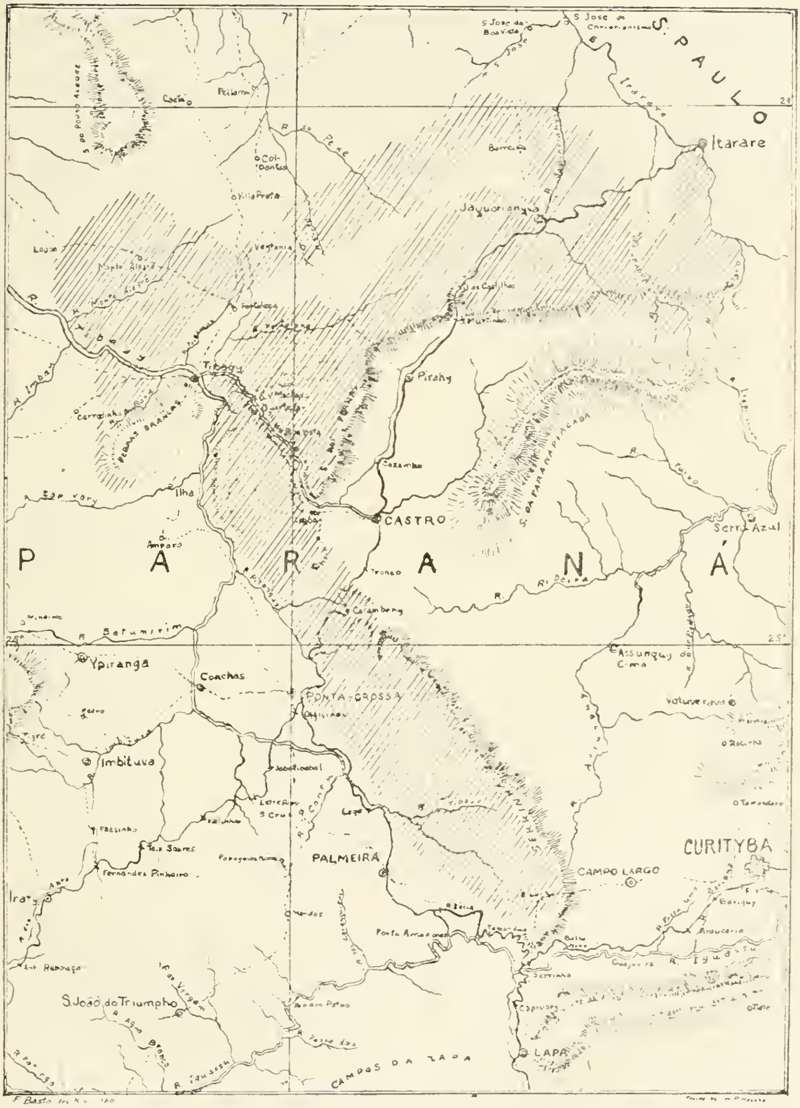

Fig. 7.— Map of the Devonian area in Paraná. The lined area is Devonian; that on the west is Permian; that on the east is the Pre-Devonian metamorphic and granitic terrane. (Published by permission of the Director of the Geological and Mineralogical Service of Brazil).

north and south of the present line of outcrop where the Permian rests upon the Pre-Devonian terrane is evidently due to erosion of the beds in Upper Devonian or Carboniferous times.

That the unfossiliferous sandstones referred to the Lower Devonian represent the shoreward facies of marine sediments is clear and it is possible that the upper part of the beds may represent shore deposits laid down simultaneously with the lower off-shore portion of the fossiliferous shales known to be of Mid-Devonian age. The thickness

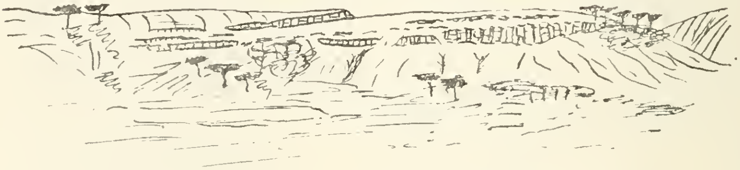

Fig. 8.— Sandstone escarpment looking northeast from Lago, Paraná.

of the outcrop of shales is however such as to indicate that they originally extended much to the eastward of the present underlying eastern limit of the sandstone just as the peneplaned surface on which the terrane rests evidently extended to the eastward of its existing traces.

The inference above stated that the Devonian shore in this region lay to the eastward is not only suggested by the westward existing dip of the beds, which attitude might be explained by a rotational tilt from an original eastward dip, but the assumption is in consonance with the basin-like form of the entire geological province of south Brazil. In Triassic times over a vast area non-marine sediments were poured on to this tract from outlying areas of land. In the preceding Permian both marine and non-marine sediments accumulated in the same or nearly the same area; and on the eastern border of the outcrop of these sediments, as will be shown later, there is evidence of the derivation of materials from an area of erosion on the east. The Carboniferous period was here one evidently of uplift or withdrawal of the sea and erosion under the atmosphere, a fact of little import on the attitude of the Devonian stratigraphic plane other than to indicate the probable proximity of land in this region in the later Devonian.

The Permian Terrane.— It now seems most likely that the strata referred to the Carboniferous in the earlier reports on this district are of Permian age. The fossil plants and few reptilian remains found

above the base of the series are without doubt referable to the Permian. The Permian strata are known along a narrow belt from southern Minas Geraes southward through the states of São Paulo and Santa Catharina; they extend into Rio Grande do Sul where the beds turn westward on the southern border of the basin-shaped area of late Palaeozoic and early Mesozoic sediments which form the central geological province of South America. Except where the Devonian beds intervene these strata rest with marked unconformity upon the Pre-Devonian rocks. According to Dr. Derby [1] the Permian consists of the following beds: —

Rocinha limestones.	3 meters.	Stereosternum bed.
Estrada Nova shales.	150 meters.	Gray, mottled shales with flints; known in Santa Catharina.
Iraty shales.	70 meters.	Black shales with Mesosaurus.
Palermo shales.	90 meters.	With fossil wood.
Coal measures.	150 meters.	Sandstones and shales with 2 beds of coal. Glossopteris flora.
Tillite beds.		
Basal beds.		Sandstones with boulders and pebbles.

Dr. I. C. White in his admirable Report [2] on the coal fields of south Brazil groups the Permian beds in the following section: —

Passa Dois series.	Rocinha limestone.	3 M.
223 meters	Estrada Nova shales with chert	150
	Iraty black shale (with Mesosaurus) [3]	70
Tuberão series.	Palermo shales	90
180 meters	Rio Bonito sandstones and shales with coal and Glossopteris flora	158
	Orleans conglomerate	5
	Yellow sandstones and shales to granite floor	27

Total thickness 403 meters or 1,322 feet.

Dr. White appears to regard the various formations of the Permian as more or less persistently parallel throughout São Paulo, Paraná,

[1] Verbally communicated at Ponta Grossa in 1908.

[2] Dr. I. C. White, Relatorio final apresentado a S. Ex. o Sr. Dr. Lauro Severiano Müller. Comissão de Estudias das Minas de Carvão de Pedra do Brazil. Rio de Janeiro, 1908, p. 33.

[3] Dr. White includes Stereosternum in this bed; but this is an error: it is found in the Rocinha limestone.

and Santa Catharina. The best defined horizon is described as that of the Estrada nova shales with flint concretions. So far as I could ascertain in 1908 the Glossopteris flora and beds of coal are only well known on the south in Santa Catharina while deposits with fossil trees are found on the north in São Paulo. The typical tillite beds are at present best known and apparently most extensively developed in the state of Paraná. On the north in São Paulo only scattered stones occur in the beds. On the south in the Tuberão Valley no tillite beds are found but waterworn conglomerates occur. Farther south and west in Rio Grande do Sul some of the reports mention boulders near the base of the section which may be presumed to indicate Permian ice-action, but tillite has not been described from there. Heretofore the Permian has shown only non-marine organic remains but the discovery of a sparse marine fauna in black shales near Rio Negro intercalated in the boulder-bearing beds demonstrates the at least temporary invasion of the district by the Permian sea. The sections traversed by the writer in São Paulo between Itaicy and Piracicaba, in Paraná between Ponta Grossa and Conchas on the Tibagy, between Lapa and the base of the Serra do Espigão, and in southeastern Santa Catharina along the Tuberão Valley, seem to bear out the above statement as to considerable variation in the character of the sediments from point to point in the lower portion of the series. The following letter shows the progress of the geological survey up to 1912.

Ponta Grossa, 13 de Dezembro de 1911.
Meo caro Dr. Woodworth.

Saude.

. . . . Estou aqui prosequindo os meus trabalhos e como sei que as suas observacões no Brasil ainda não estão publicadas aproveito esta para lhe dar algumas indicações sobre a idade dos conglomeratos glaciaes.

A primeira vez que encontrei camadas com fosseis marinhas em conglomeratos glaciaes foi quando eu estava executando a sondagem do Passinho a 12 km. ao sul de Imbituvo. Estas camadas foram encontradas a partir de 120 metros de profundidade; tinham 45 metros de espessure e nellas achamos uma pequena lingula, escamas de peixes, e restos indeterminados de brachiopodos e lamellibranchios. A partir de 160 metros de profundidade a sondagem atravessou atè 395 metros exclusivamente camadas argillosas, sem estratificação, com pequenos seixos, e algumos boulders de granito. Em 1908, na sua companhia descobrei a camada fossilifera do Rio Negro. E' um schisto negro, ardoriano, com Lingulas, Discina, peixes e restos de esponjas. Em Outobro deste anno consequi identificar as camadas da sondagem do Passinho. Ellas apparecem no grotão leste de T. Soares, 45 metros abaixo do arenito

amarello com seizos que ahi conteim uma delgada camada de plantas fosseis. A secção e' a sequinte:

Arenito amarello com delgado leito de carvão	50. metros.
Argilla negra com abundantes restos de insectos . . .	0.60
Schisto cinzento com rica flora de Glossopteris	5.0
Schisto cinzento um tanto ardoriano contendo Lingula, Discina, escamas de peixes, azas de insectos, Chonetes em abundancia, e outros brachiopodos	40.
Camada argillosa com seixos e boulders atè o rio das Almas .	60.

....Parece-me não haver duvida de que o conglomerate e' Carbonifero medio ao Permiano. Os insectos apparecem não sò nas camadas marinhas como as que se acham logo abaixo do carvão.

Esta vista modificada podrè figurar em seu relatorio.

Abraços, o amigo admirador,

Euzebio Paulo de Oliveira.

(Translation by J. B. Woodworth).

Ponta Grossa, 13th December, 1911.

My dear Mr. Woodworth,

Greeting:

......I am here prosecuting my labors and as it may be that your observations on Brazil have not yet been published I avail myself of this opportunity to give you some data upon the age of the glacial conglomerates.

The first time that I found beds with marine fossils in the glacial conglomerates was when I was executing the boring at Passinho 12 kms. south of Imbituvo. These beds were encountered on going below a depth of 120 meters: they were 45 meters thick and in them we found a small Lingula, scales of fishes, and remains of undetermined brachiopods and lamellibranchs. Below 160 meters in depth the boring traversed down to 395 meters exclusively shaly beds, without stratification, with pebbles and some boulders of granite. In 1908, in your company, I discovered the fossiliferous bed on the Rio Negro. It is a black, combustible shale, with Lingula, Discina, fishes and remains of sponges. In October of this year I found the equivalent of the beds of the boring at Passinho. They appear in the ravine east of T. Soares, 45 meters below the yellow sandstones, with pebbles, that here contain a thin bed of fossil plants. The section is as follows: —

Sandstone, yellow, with thin layer of coal,	50. meters
Shale, black, with abundant remains of insects.	0.60
Shale, ashy, with rich flora of Glossopteris.	5.00
do do somewhat burnable, containing Lingula, Discina, scales of fishes, wings of insects, Chonetes in abundance, and other brachiopods.	40.00
Argillaceous bed with pebbles and boulders down to the river das Almas	60.00

....It appears to me not to be doubted that the conglomerate is Carboniferous intermediate to the Permian. The insects appear not only in the marine beds but in those which occur immediately below the coal.

This view modified may figure in your report.

Cordially yours,

Euzebio Paulo de Oliveira.

Dr. Derby, in 1888, in a letter to Waagen, which was published by that geologist (Derby, 1888) announced the occurrence in this series of erratics and likened the deposits to those of the glacial beds of the

Permian in India and Australia, a view which every subsequent geologist who has attentively examined the evidence in the field has concurred in. (I. C. White, 1908).

The identification by Mr. David White (in I. C. White, 1908, p. 281, etc.) of the Glossopteris flora in the shales of the coal measures of Santa Catharina has completed the evidence as to the Permian age of those beds. In the correlation made with the Permian of India and elsewhere by Mr. White, there is a satisfactory agreement. In south Brazil as elsewhere the tillite beds occupy a position inferior to the main occurrences of the flora.

Though mainly of non-marine origin, the Permian sandstones and shales as well as the glacial beds were deposited at or near sea-level. Further consideration of the geographical conditions of the period is deferred to the sections dealing with the conditions of Permian glaciation.

The Triassic Terrane.— Surmounting the Permian strata of south Brazil there comes a group of mainly red beds with great sheets of trap forming its highest members. The basal beds of this series have afforded the remains of the Triassic reptile Scaphonyx and of fossil wood. The series is apparently in unconformable relation to the underlying Permian. According to Dr. Derby the beds on their northern limits overlap the Permian and rest upon the Pre-Devonian terrane. The series in most respects recalls the Newark group of Upper Triassic age in eastern North America.

According to Dr. White's report (1908, p. 33) the Trias is comprised of the following members: —

São Bento series. 900 meters	Serra Geral eruptives . . .	600 M.
	São Bento sandstones, red, gray, and cream colored beds . . .	200
	Rio do Rasto red beds with Scaphonyx and fossil wood . . .	100

The reports are not always explicit as to the nature of the trap sheets. Though apparently generally regarded as lava-flows Dr. White speaks of examples in southern Santa Catharina and Rio Grande do Sul in terms indicating the existence of thick sills. In this region, he also describes the underlying beds as intruded by great irregular dikes as if they were feeders to some of the overlying trappean masses. In general the Triassic area forms in south Brazil an elevated plateau attaining elevations of 4,000 feet faced where it overlooks the Permian tract by an escarpment crowned with sheets of basalt. The eastern

border of the Triassic formation thus constituted is deeply notched by the greater rivers, such as the Iguassú. The escarpments lying like great loops on the eastern limits of the formation between these river valleys receive various names such as the Serra Geral, the Serra da Esperança, etc. Siemiradzki in a section reproduced by Suess gives a somewhat different interpretation to the trap mass of the Serra da Esperança, but the section of the same field credited to Derby is in harmony with the structure here described as is also the section traversed by the writer between Rio Negro and Lages in Santa Catharina. Further consideration of the Triassic rocks and their bearing on the climatic conditions succeeding the Permian glacial epoch are reserved for a following chapter.

The Tertiary Deposits.— Whether or no the Cretaceous deposits covering the border of the continent south of the Amazon have representatives now in some of the sands and clays of the coastal border south of Rio de Janeiro, there are rather recondite reasons for believing that such deposits may once have flanked the coastal slope of the Serra do Mar province; if so they were not long after their deposition worn away. On the upland or planalto, to use the Brazilian name of the plateau region, no known deposits occur between the Trias and certain sediments in São Paulo which from their fossil fishes are shown to be of fresh-water origin and Tertiary in age. These deposits are most extensively developed in the valley of the Parahyba between the Serra da Mantiqueira and the Serra do Mar and in a smaller tract underlying the city of São Paulo. In these cases, the beds occupy not well understood depressions in the Pre-Devonian terrane. In what follows on the topography of the plateau, the occurrence of these non-marine deposits will be advanced as evidence of a change of attitude of the region in late Tertiary times.

General Structure of the South Brazilian Permian Area. It remains to describe the general structure of the region embracing the states from São Paulo southward to Rio Grande do Sul. A glance at the geological sketch map, Plate 15, shows that this region has been warped in Post-Triassic times. A broad synclinal structure with its axis in an east and west direction occupies southern Santa Catharina and northern Rio Grande do Sul, causing the Permian and Triassic in turn to approach the Atlantic coast; and, because of the depression of the beds towards the synclinal axis, they attain sea-level and in the case of the Permian descend below that level. On the north of this structure a complementary anticlinal axis is less well defined in central eastern Paraná. Its position is marked out by the arcuate trend of

the Devonian sandstone cuesta in the Serra das Furnas and by the Serra da Paranapiacaba.

That this gentle broad warping of the Post-Devonian strata is of Post-Permian date is shown by the sinuous trend of the outcrops of the Permian terrane. That it is Post-Triassic is also indicated by the down bending of the trappean sheets in the syncline on the south. Precise evidence of a local nature is apparently lacking to demonstrate how long after the completion of the local Triassic section the deformation was produced. The dislocation of the Triassic Newark beds of eastern North America in presumably early Jurassic time would lead us to admit that the deformation of south Brazil may have taken place at this time. For topographical reasons set forth in the account of the physiography of this region (p. 99) it seems that this type of deformation took place in Pre-Cretaceous times. A Jurassic date for the deformation thus appears the most probable one.

Summary of Geological History of the south Brazilian Plateau.— From this brief account of the geology of the south Brazilian plateau it appears that, long prior to the Devonian period, the region passed through a series of changes registered in the occurrence of igneous and metamorphosed sedimentary rocks as yet little understood. At least one series of sediments now slates and limestones involved in the complex may be the equivalents of the Ordovician or Cambrian strata but fossils are wanting to prove the age of these beds. The basal Devonian sandstones resting on the eroded edges of these metamorphosed and intrusive rocks can only be interpreted as evidence of land conditions in the epoch preceding the Devonian and hence in the Silurian (Upper Silurian of Murchison). The Devonian sea transgressed the area and continued depositing sediments through the middle of that period. Whether deposition took place in the Upper Devonian is not now clear. The Carboniferous period was so far as the records go one of land denudation in which most of the Devonian was swept away. The extent of this denudation is such as to render it probable that higher Devonian beds originally overlay the Middle Devonian shales of Paraná.

True Carboniferous deposits appear to be wanting in the area, such strata as may have been referred to this epoch belong rather to the basal Permian.

The Permian is characterised by a series of mainly non-marine formations laid down at or near sea-level with locally well-developed beds of tillite indicative of a glacial period. Elements of the Glossopteris flora have been found in Santa Catharina in shales which carry

thin beds of coal. The lower members of the Permian section display no marked persistence north and south but towards the top of the section more uniform conditions of deposition appear to have prevailed. The horizon of the Iraty black shales near the top appears to be fairly continuous.

The so-called Trias characterised by red beds and contemporaneous basaltic outflows and intrusions marked a great change of geography and climate. Arid conditions succeeded to the moist climate of the Permian but stream action appears to be demanded for the deposition of the thick sandstone beds devoid of marine fossils. Presumably at the close of the Triassic episode of deposition and at some stage in the Jurassic period the region underwent gentle warping producing the present structure of the plateau.

The Jurassic and Cretaceous periods are in this region without existing remnants of deposits. If the elevated Cretaceous marine beds of the north originally extended so far south, it is to be presumed that they were preceded by an epoch of baselevelling and in the following Tertiary time by the uplift of the district in such a manner as to give rise to the Serra do Mar slope to the sea-floor. Erosion of the plateau surface and of the short slope to the sea has worked out in accordance with the specific resistances of the several terranes the existing topography of the region, with a late Tertiary interruption of the cycle of erosion indicated by small basins of non-marine Tertiary beds in São Paulo. Over this surface a mantle of unconsolidated materials produced by weathering with more or less transportation has accumulated during Pleistocene and Recent times.

The annexed cross-section of south Brazil, after Derby, exhibits the essential features of the structure of the plateau in the latitudes where the Devonian strata occur.

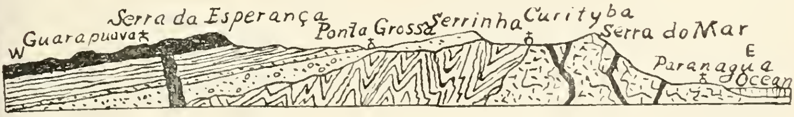

Fig. 9.— Geological cross section of south Brazil (after Derby).

For a bibliography of Brazilian geology, the catalogue of publications prepared by Prof. J. C. Branner (1909) should be consulted.

V. PERMIAN GLACIAL DEPOSITS OF SOUTH BRAZIL.

"In the next great section of the earth's crust, the Permian period, we have an almost world-wide extension of glacial waste * * * Even in the Southern Hemisphere we have what seems to be conclusive proof that the glaciers during this age operated in regions nearer the equator than they did during the last glacial period."

Shaler in *Shaler and Davis. Glaciers,* Boston: 1881, p. 96.

"Evidence is slowly accumulating which serves to show that glacial periods of greater or less importance have been of frequent occurrence at all stages in the history of the earth of which we have a distinct record."

N. S. Shaler. *Outlines of the Earth's History,* New York: 1899, p. 247.

The foregoing statements concerning the boulder-bearing Permian beds of south Brazil show the state of the inquiry concerning the origin of these deposits as late as 1908. Dr. Derby, Professor Branner, and Dr. I. C. White were essentially in agreement in regarding as highly probable the glacial origin of the boulders, but striated rock surfaces either of the bed rock or as transported erratics were wanting.

The boulder-bearing beds of the Permian in south Brazil are far from presenting a persistent parallelism of strata from point to point along their outcrop. In the state of São Paulo the typical tillite is seemingly wanting except near the southern border, the evidence of ice-action being limited largely to argillaceous sandstones carrying occasional stones and boulders. The typical tillites crop out on the northern border of the state of Paraná and are exposed at what appears to be more than one horizon as far south as Santa Catharina. In eastern Santa Catharina in the section along the Rio Tuberão there are no surface exposures of tillite, but waterworn conglomerates occur at a low horizon in the section apparently representing as at Ponta Grossa in Paraná the glacial episode.

The following account of the sections studied by myself begins with the beds on the north in the state of São Paulo, and includes the following sections: —

a. The section from Itaicy to Piracicaba in São Paulo.
b. The section on the Rio Jaguaricatu in northern Paraná.
c. The section from Ponta Grossa to Conchas, Paraná.
d. Exposures between Ponta Grossa and Serrinha, Paraná.
e. The section from Serrinha via Lapa to Rio Negro, Paraná.
f. The Orleans-Minas section in the Tuberão Valley, Sta. Catharina.

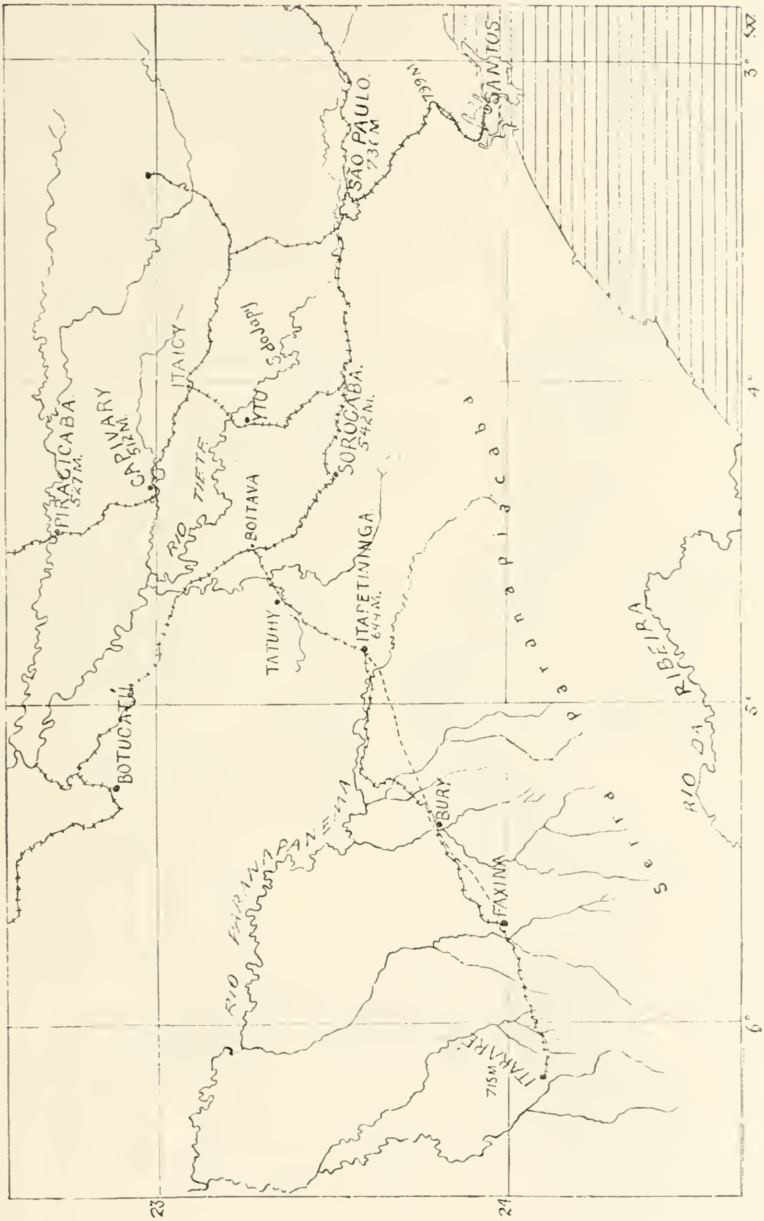

FIG. 10.— Sketch map of southeastern part of state of São Paulo.

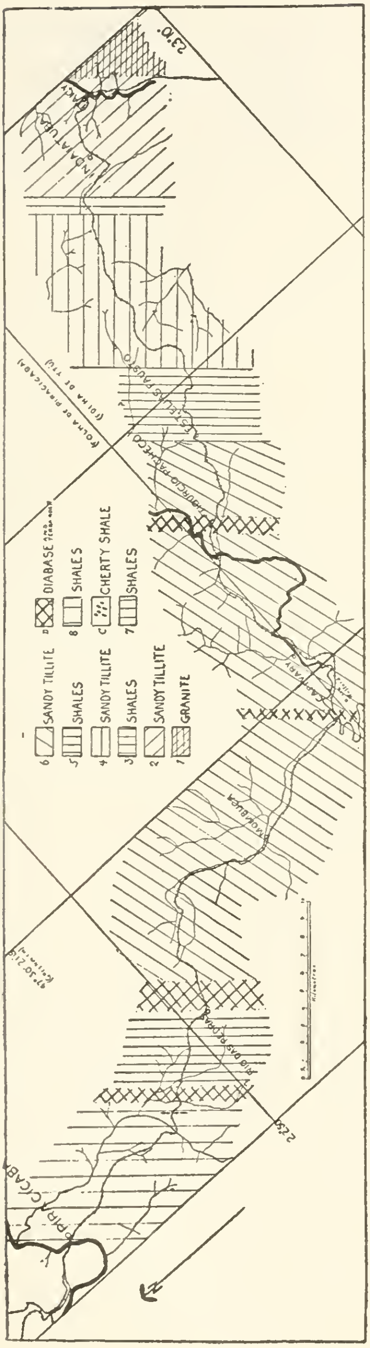

Fig. 11.— Sketch map of Permian along railway line between Itaicy and Piracicaba, São Paulo. The projection of the strata beyond the line of route is subject to correction for topographic relief.

The section from Itaicy to Piracicaba: — A reconnaissance was made of the section from the granite base at Itaicy along the railway upwards in the series to Piracicaba. The following rough notes serve to bring out the general character of the strata below the reptile-bearing Permian horizon at the latter place and have been made the basis of the accompanying section and sketch map. The station numbers are those of the kilometer posts along the curving and locally recurved line of the railway. Notes and posts are given in the order in which they came. Itaicy has an altitude of 1,200 M. (1,870 ft.) according to local contour of the map.

151. Granite boulders; in place (?).
153. On sediments. No boulders noted.
One stone in yellowish topping.
Cut with pebbles; shale over sandstone.
154. . . . .
Reddish massive sandy shale (now clay).
Pebbly sandstone; no striae seen on pebbles.
155. . . . .

156. near
Indaiatuba (Indaia, wild fruit; tuba, many).
157. Canga (limonitic crusts).
Bridge.
158. ....
Reddish sandstone.
159. ....
Shales.
Crew house. Boulder on surface.
Massive checkered clays (shales).
Surface covered with cobbles.
160. ....
Small overturned fold south side of track in strongly folded shales. Beds dip N. W. Dark shale bed.
161. ....
Cut showing yellow sandstones above last.
162. Cut, with cobblestones in shales.
Cut with sandstones.
do.
163. ....
Deep cut, sandstones without pebbles.
164. ....
Boulder on surface.
165. Red cut.
166. Long cut; red sandstones without pebbles.
167 to 169; no exposures.
Red beds with pebbles.
170–171. Folded yellow tillite (?) bed.
Shaly sands now clayey.
172. ....
Red shallow cut.
173. do.
do.
174. ....
Bouldery shales; 2 ft. boulder of quartzite. Also diabase sill? Small fault running east-west; downthrown to west.
Black band bed. Carbon or manganese?
175. ....
Shale.
176. ....
Black shale.

177 to 178; no exposures.
Boulder near Elias Fausto; ca. 2 ft. size.
Shales.
179. . . . .
Tillite or sandstone; boulders loose on surface.
180. Long cut in sandstone.
Yellow clayey sandstone to
181. . . . .
182. . . . .
Cut in diabase sill.
Tillite sand on top of diabase.
183. do.
184. . . . .
Diabase sill to Tuburcio Pacheco Station.
Yellow beds with stones.
185. Tillite?
186. Rio Capivary.
Dark shales with embedded stones.
187. . . . .
Tillite section, in which I find large angular piece with faint striae; rock a compact white sandstone; like the bed under the Jaguaricatu beds.
Waterworn pebbles in a layer overlaid by reddish sandstone but these beds are possibly Post-Palaeozoic. S. E. of Faz. Barreiro.
188. . . . .
One or two boulders seen on surface.
189. . . . .
Black shale; greenish black, containing in cut at least one granite boulder 15 to 18 inches (38 to 45 cm.) long; continue to cross-roads; there overlying
190. Sandstones.
Yellow fine sandstones (loessite?)
191. . . . .
Similar to last; faulted and disturbed; small overthrust of sandy loessite upon shales.
193. . . . .
Massive beds of sandstone.
Rio Capiavary near to
194.
195. Near to Capivary Station.
196. . . . .

Loessite with boulder; sandstones with small vertical fault; downthrow to east.

197; Good cut with two small overthrust faults; overthrust eastward.
Yellowish sandy shale.
Tillite; fine grained.

198. ....

199. Sugar factory at Villa Rafford.
In cut beyond station, tillite with boulder of conglomerate (Plate **20**). Pebbles in boulder mainly quartzite.

200. ....
Trap near to

201. ....
Trap.
Tillite.

202. ....
Sandstones.

203. Cut.
Boulders and stones in sandy beds.
Shales; somewhat crumpled.
Dark shales to

204. ....
Sandstones.
Shales; with concretions (?).

205. ....
Tillite, with stones.
Long side cut here with sandstones like moulding sands; containing boulders of granite and quartzite.

206. Till-like sandstone.
Red do.
Beds with pebbles and small blocks.

207. ....
Tillite? without pebbles.
Beds of characteristic yellow, and with bale structure; stones rare and small. Beds flat, to near

208. ....
Same as last.
Chert pebbles appear in surface deposit
Pebbly sandstones in cut.

209. ....
Sandstones in long cut.

210. do.

Same to Mombuca Station.
211. . . . .
Shaly bed.
Pebbly sandstone (tillite?) near
212. . . . .
do.
do.
213. . . . .
Two cuts of same.
204. do., in good cut. No stones seen.
215. Glacial sandstones.
216. do. fine grained.
Fine mealy sandstones.
do.
217. do.
Steep dip locally to northeast?
218. Shales; thin?
Red sandstones over last.
Boulders on surface.
Purple shales.
Boulders on surface.
Red cut. Trap?
219. . . . .
Brownish red rock in cut; trap.
220. do.
221. Cut in sands red to brown in color.
Terra roxa; deep cut.
222. do.
Trap near
223. *Terra roxa* cut.
224. do.
Sandstones.
225. . . . .
Stratified beds, glacial sandstones and shales.
Rio das Pedras Station.
226. . . . .
Purplish to reddish alternating sandy layers in cut.
Shales with sand band.
227. Shales.
do. greyish.
do. dark colored.

228. ....
do.
do. with thin sandstone bands.
229. ....
do. purple.
Sandstones?
230. ....
Red cut; bright red; *terra roxa?*
231. ....
do.
Shales, purple, under red bed.
Cherty layer, vesicular, from 1 to 1.5 inches thick; in shales near
232. ....
Red bed.
233. do.
234. do. *terra roxa?* mixed with sand?
235. do.
236. do. near
Purple shale (diabase sill above?).
237–238.
Red cut.
Chert beds.
Stratified purple shales; dip northwest.
239. ....
Sandstones and purple shales, thick, interlaminated.
240–241.
Piracicaba Station.

Without deep borings it is hardly possible to obtain an accurate measurement of the thickness of the strata in this section from Itaicy to Piracicaba. Any estimate is increased a slight amount by the small overthrust faults, for which a deduction should be made, though in round numbers this is possibly a negligible quantity. There is also the question of the uniformity of the dip of the beds. The small contortions associated with the little faults demonstrate the existence of some Post-Permian disturbance of the beds, mainly an eastward overthrust. From kilometer post 189 to the cross-road between that post and 190 kilometers, there is a bed of greenish black shale which appears to overlie as in a shallow synclinal fold the glacial sandstones on the respectively south-east and north-west of the exposure. This point is 8.5 kilometers north-west down the supposed dip from the

eastern limits of the Capivary sandstone group. If this interpretation of the structure be correct and the shale bed does not dip into the section immediately westward of this exposure, the question is raised whether it is not a southeastern outlier of the shales which certainly overlie the group westward from Rio das Pedras. In this case the sandstone beds northwestward from Elias Fausto to this shale outcrop instead of being 1,400 feet thick would have a thickness not greater than that of the second belt above the base, *i. e.* about 600 feet. This would reduce the total thickness of the section measured from 4,000 ft. to 3,200 feet.

As for the maximum thickness, neglecting the above possible causes of diminution in the estimated thickness, there is the presumption that the sill of diabase which crops out between the 230 and 231 kilometer posts in the form of a bright red *terra roxa* zone represents the trap sheet which forms the falls in the river at Piracicaba. The upper contact of this layer on the southeast is near the 575 M. contour; on the northwest down the dip at the river it is somewhere near 525 M., giving a drop of 50 M. in 7.5 kilometers or thirty-five feet to the mile, which is equivalent to a little more than a dip of 1° to the northwest, and since the strata overlying the sill are presumably parallel to the plane of the sill, we have in this part of the section an estimate of the dip. Again the thin bed of shales at and southeast of Elias Fausto Station have a breadth of outcrop of four kilometers (2.48 miles, say 2.5 miles). Their base on the east along the line of the railway is at about the 600 M. line; their top at the northwest at 575 M. giving a fall of the surface of twenty-five M. in four kilometers or eighty-two feet in 2.5 miles, or thirty-two feet to the mile. Assuming the shale bed to be at least ten feet thick, we should have dip of thirty-six feet to the mile, which considering the approximations on which the estimate is based is in close accordance with the estimate of the dip made for the beds immediately southeast from Piracicaba.

On the assumption of continuity of bedding and dip from the base at Itaicy to Piracicaba, a dip of 1° would give a minimum thickness of 1,145 M. or 3,700 feet for the total thickness from the base to the Stereosternum beds.

Rough calculations of the mainly sandstone group at the base about Imbaiatuba with a breadth of outcrop of 5.76 M. or 4.19 miles gives an estimate of 436 feet for their thickness, with a maximum of 700 when scaled to the maximum estimate.

The succeeding shale bed 153 feet as a minimun, 226 as a maximum.

The second group of sandstones may be estimated as having at the minimum a thickness of 400 feet, a maximum of 600 feet.

The shales at Elias Fausto Station, by the minimum estimate fifteen feet, by the maximum twenty-two.

The succeeding group composed mainly of sandstones including all the beds about Capivary, by the minimum estimate based on the hypothesis of duplication of exposure through gentle folding 600 feet, or by the maximum 1,400 feet.

From the top of these beds to the shales with Stereosternum at Piracicaba 700 feet by the minimum, 1,000 feet by the maximum method.

These minimum estimates give a thickness of 2,343 feet, or about 714 meters.

The Bofete-well record in São Paulo cited by Dr. I. C. White gave forty-eight M. for the Iraty Black shale and 837 feet below that group to the bottom of the well.

The accompanying section (Fig. 12) represents the succession of strata between Itaicy and Piracicaba interpreted on the probable solution that the shales east of the Rio das Pedras are in a synclinal outlier of the beds about Piracicaba.

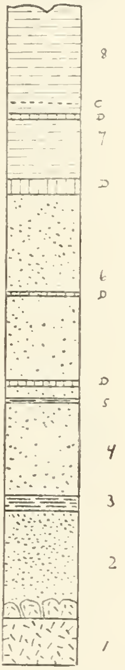

Fig 12 — Section of Permian from granite floor at Itaicy to Piracicaba. 1. Pre-Devonian granite. 2. Sandy tillite about Imbaiatuba. 3. Shales. 4. Sandy tillite. 5. Shales at Estação Elias Fausto. 6. Sandy tillite east and west of Capivary. 7. Shales west of Rio das Pedras. C. Cherty layers. 8. Shales and Stereosternum beds about Piracicaba. D. Diabase sills.

In this section there appears no bed equivalent in lithological character to the boulder tillites of the Jaguaricatu section in northern Paraná. In the section along the line of the railway there are scattered stones and small blocks embedded indifferently in the peculiar sandstones and shales. This indiscriminate distribution of frequently striated stones in beds of sandstone and shale is presumptive evidence of the action of floating ice particularly in the case of the shales. The weathered state of the sandstones in the railway cuts makes precise comparisons with the deep[1] blue tillite beds farther south difficult and unsatisfactory.

So far in this section of the Permian no marine fossils have been found below the Stereosternum beds if indeed that horizon be marine. On the contrary, notwithstanding the trunks of trees discovered by Dr. Derby somewhere near the middle of the section, no fossils appear

to have been found in place; but the tree trunks cannot be far out of position, and the general character of the section points to the sub-aerial accumulation of certain of the sandstones in the manner of outwash plains such as now accumulate in front of glaciers or in similar situations permitting the growth and fall of trees between times of aggradation by débris-laden streams. Only a detailed survey of the region would suffice to determine more definitely the relations to sea-level and the existence of lenses of tillite in the section.

Tillite Beds on the Rio Jaguaricatu in Paraná. Sengéns is a station on the newly constructed line of railway from Itararé to Jaguariahyva in northeastern Paraná, on the south bank of the Rio Jaguaricatu. In the railway cuts which were fresh in 1908 good sections of the glacial boulder-clays or tillite were exposed for several kilometers in either direction. The Station is near the 228 kilometer post. The following notes pertain to the exposures along the curving course of the railroad which follows down the right bank of the river towards São Pedro de Itararé. Near post 234 a well-striated sandstone pebble was found dislodged from a sandy conglomerate or tillite at this locality. This pebble is shown in Plate **21** to the left of the hammers. The striated surface is well flattened and the edges battered off. It displays no zigzag striae and may be a fragment of the old glaciated floor. Somewhat farther to the northeast between posts 234 and 235 the boulder-clay type of tillite is well shown, as in Plate **21**, there containing small boulders of granite.

Between posts 235 and 236 apparently near the top of the local bed the view shown in Plate **22** was taken. At this point in a fresh railway cut there is exposed an angular slab-like block of a fine grained white sandstone resembling novaculite, nine feet (three meters) long and about twenty-one inches thick, the third dimension not being ascertainable, the largest angular block I myself saw in any section in Brazil. This rock is practically identical, lithologically, with a white sandstone layer which occurs lower in the section at a locality along the railway where a fault brings the beds towards the surface. (Fig. 13).

This fault extends in a northwest direction and the downthrow appears to be towards the west. The sandstone in question is here overlaid by pebble beds. Between these eastern exposures and Sengéns there are coarse sandstones containing at least one pebble bed with a greater proportion of granitic pebbles than are found in the more typical tillite of the district. From this pebble bed I collected three stones carrying faint striae.

West from Sengéns on the north of the Rio Jaguaricatu in one of the deep cuts along the ascending grade striated stones were first found in Brazil. The bed exposed at this locality is a typical tillite, containing large subrounded masses of a whitish rock resembling the

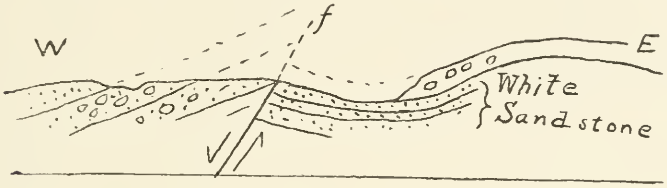

Fig. 13.— Section along the railway showing white novaculitic sandstone bed under tillite bed.

white, fine, silicious sandstone from near the base of the Permian section.

This occurrence of the fine white sandstone in the boulder-beds from São Paulo southward in close association with the preglacial stratum of the same character is strong evidence of the eastern derivation of the erratics.

Conglomerates at Ponta Grossa: — Overlying the trap-invaded fossiliferous Devonian shales which underlie the "big point" between

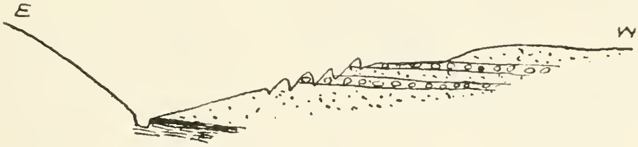

Fig. 14.— Section of Permian conglomerate beds in vicinity of Ponta Grossa, Paraná.

streams on which the city of Ponta Grossa stands, there are to be seen on the northwest of the town near the base of the Permo-Carboniferous series, at least two beds of waterworn conglomerate (Fig. 14) interpolated in a thick sandstone series. These waterworn pebbles present in themselves no evidence of glacial origin or transportation. The lower pebble bed, from four to five feet thick, is made up of subangular to well rounded, waterworn, light-colored sandstone pebbles from .5 inch to 6 inches in diameter. Rarely larger cobble-

stones occur at the top of the bed embedded in the overlying sandstone. No glacial striae or facets were seen on any of the exposed pebbles. Besides the sandstone pebbles, I saw one of micaceous quartzite, a crumpled phyllite, a whitish chert, a red argillaceous sandstone, a decomposed granite with reddish feldspar, a silicious schist, *in toto* a variety of rocks indicating the derivation of at least a small portion of the débris from the Pre-Devonian terrane. The pebbles could hardly have been transported far by water action alone, because the sandstones pebbles are of a sort which do not wear well in any stream journey. I estimate their journey as stream pebbles to have been tens of miles rather than hundreds of miles. The assemblage of these pebbles in a well-stratified bed between layers of a coarse-grained sandstone leaves no doubt of water action. A few feet of sandstone separates this bed from the one above, in which the sandstones pebbles again formed the predominant constituents but were noticeably more rounded than the crystalline pebbles. Dr. I. C. White mentions in his Report a bed of boulders at Ponta Grossa and a deposit containing fossil wood, but I saw none, nor were such deposits known to the Geological Survey staff at the time of my visit.

Tillite Bed at Conchas: — Conchas lies on the north side of the Rio Tibagy about four leagues west from Ponta Grossa. On the south of the village a small quarry was opened some years ago in a grayish somewhat indurated stony clay bed, a boulder-clay phase of the tillite beds. The scattered pebbles consist of silicious rocks and rarely a granitic pebble. The bed fractures with a giant ball structure (Fig. 15). No striations were seen on the pebbles. The mode of occurrence of the pebbles seems best explained by dropping from floating ice and probably the clay with its sand grains of irregular size originated in the same manner. The rock when exposed to the weather breaks down by a process of checking and the opening of ragged fractures into smaller and smaller blocks so that it is valueless for building stone.

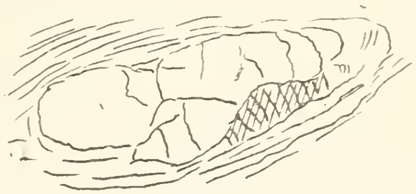

Fig. 15.— Fracture of the tillite bed at Conchas.

This bed overlies the sandstones with waterworn pebbles at Ponta Grossa, and recalls in its lithological characters the beds on the south of the Rio Jaguaricatu east of Sengéns and also the beds southeast of Rio Negro.

Signor Cicero de Campos (1908, p. 3) of the Brazilian Geological Service states that between the port of the Indias and Salto-Maua in Paraná there outcrops a little below the falls on the left bank of the Rio Tibagy a yellow sandstone with enormous blocks of pink porphyry granite and of porphyry. The fall is caused by basalt. Campos refers the strata of the hilltops to the Carboniferous (Permian?).

Near the sixty kilometer post on the railway from Ponta Grossa to Porto da União I noted an exposure of the compact yellowish beds which appear to be the weathered phase of the tillite as at Conchas. A large boulder was also seen in a cut a short distance north of this locality.

Boulders and Pebble Beds near Palmeira.— On the divide south of Palmeira yellowish compact beds with blackened joints exhibit a few pebbles north of the 133 km. post. These beds continue in the railway cuts to and somewhat beyond the 130 km. post, then laminated yellow beds come in and a boulder about three feet (1 meter) in diameter appears on the surface west of the track near a house north of 128 km. post, about eleven kms. north of Restinga Secca Station. Large blocks appear in a cut between 122 and 121 km. posts, north of branch road to Amazonas. Beyond 105 km. post, pink pebbly beds are intersected by the railway in the long descent, with tilted pebble bearing beds near 103 km. post. Tilted beds also occur near the ninety-nine km. post, possibly faulted beds. Tamanduá Station is at the ninety-three km. post. Beyond this Station pebbles occur in sandstone at eighty-five km. post; again at eighty-three km. post. At seventy-eight km. post there is a good pebble bed and north of seventy-six kms. gravels appear in a cut.

The Glacial Conglomerate at Serrinha.— At Serrinha in the gorge of the Iguassú, where that river has cut deeply into the sandstones at the southern limits of the sandstone cuesta locally known as the Serrinha (little serra), there is a good exposure of beds, the general characters of which are shown in the annexed unmeasured section, (Fig. 16).

There is here east and west of the railroad station an exposure of small pebbled conglomerate rising about twenty-five feet above the level of the track. Quartz pebbles either angular or well rounded occur in this bed, with occasional pebbles of gneiss and possibly granite, together with quadrangular fragments of a now reddish friable sandstone, presumably a rock derived from underlying beds. East of the station between the 69th and 70th kilometer posts, Dr. Euzebio Oliveira found in the conglomerate beneath the sandstones a dis-

tinctly striated pebble, a compound quartz-bearing rock, with one well-rounded side and a surface of more recent fracture. The rounded surface bore striae. The pebbles in this conglomerate are

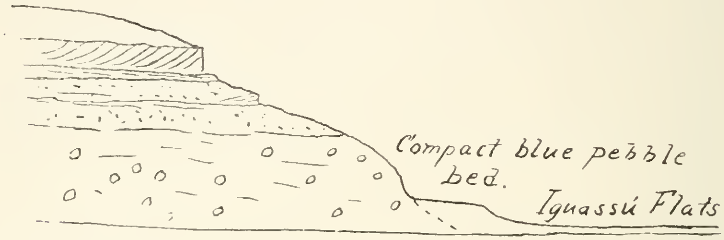

Fig. 16.— Section of the conglomerate and overlying sandstones at Serrinha, Paraná, in the gorge of the Iguassú.

rather closely scattered through a matrix of abundant sandstone of an argillaceous character, suggesting the deposition of the mass by floating ice.

The whitish sandstone overlying this conglomerate is so like that forming the base of the Devonian northward in the Serrinha ridge that the question is raised whether this conglomerate belongs to the Permo-Carboniferous series or to the Devonian. There is no appearance of faulting in the neighboring district which I discerned. The Devonian shales which separate the Devonian sandstone from the basal Permian at Ponta Grossa on the north have at this distance on the south disappeared, and it is possible that the Sandstone has also; the Permian by overlap coming close down to if not in contact with the Pre-Devonian east and north of Serrinha, the local resemblance of the white sandstone to the typical Devonian being assignable to a redeposition of those sandstones. The determination of the Devonian age of the lower beds at Serrinha, should it be made, would introduce another glacial epoch in south Brazil parallel to the case in South Africa. In this report I have preferred to follow the tentative opinion of Dr. Derby that the Serrinha section is Carboniferous (Permian). This view involves at least two advances of the ice in Permian time.

The Section at Lapa.— Lapa is a station on the railway south of Serrinha. Along the line of railway southward from Serrinha after surmounting and crossing the sandstones on the south bank of the Iguassú the tillite beds are traversed by the train. Near and north of Pivary the campo surface is strewn with rounded stones. About

a mile east of Lapa the Morro do Monge (Monk's Hill) rises, the most northern of a series of sandstone ridges forming a line of westward facing escarpment, broken down at intervals by cross-valleys presumably of structural origin. This sandstone overlies the tillite beds, and is traceable in these ridges southward to the Rio Negro, south of which it plunges beneath higher beds, in which, as will be shown, isolated boulders are not wanting. At the base of the Morro do Monge sandstone, there is a ferruginously spotted variety, which is locally quarried. At the surface it weathers into fist-sized quartzitic knobs. At the top of the tillite series and beneath this sandstone at the northeast angle of the Morro do Monge, where the road crosses, there is a conglomerate bed about five feet ($1\frac{1}{2}$ meters) thick with rounded pebbles in a sandy matrix. This is overlain by one foot of sandstone, then by a bed with scattered pebbles and sandstones. In this series I found a polished quartzose pebble with faint striae. Further south along a private road on the west face of the Morro and at about the same horizon as the conglomerate beneath the sandstones I found a loose pebble of striated sandstone, a specimen of doubtful indications. Striated pebbles in this locality at this horizon are rare.

Between Lapa and Rio Negro.— South of Lapa the train runs over the yellow weathered surface of the tillite beds. In a cut between kilometer posts 51 and 52 one or more thin sills of diabase appear. South of the Rio Vargem the train ascends one of the sandstone outliers which is deeply dissected by streams. Between the 73rd and 74th kilometer posts on the descent to the valley of the Rio Negro, just under the hard sandstone bed, in a cut a well-defined boulder-bed appears. Some of the rounded masses have a diameter of three feet (1 meter). Occasional cobbles and yellow compact weathered beds at lower levels farther south indicate the continuance of the tillite sands in this direction.

Localities near Rio Negro:—About two miles north of the city of Rio Negro on the northwest bank of a stream which falls into the Rio Negro there is a high bluff of laminated shales with a pronounced concretionary structure with very small intersecting joints. These shales carry scattered pebbles at various levels, the pebbles ranging up to six inches in diameter. One of these larger pebbles showed a smoothened sole or side and faint striae. These shales lie above the sandstone at the bridge over the Rio Negro at the city of that name. Some of the pebbles are a hard sandstone; mica schist also occurs. Most of the pebbles were partly rounded, resembling kame and esker pebbles rather than typical stream pebbles. A flattish broken edged piece of sandstone also showed weak striae of glacial character.

Sandy beds with boulders succeed to the shales for a few feet of thickness. Shales come in again above this level, rarely with striated pebbles.

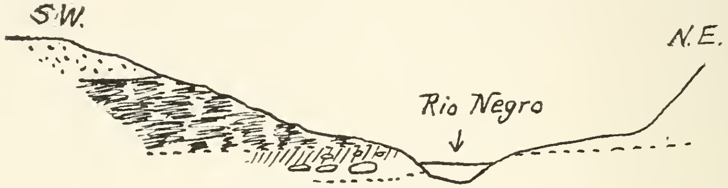

Fig 17.— Section of Permian shales, boulder-beds, and sandstones at Rio Negro.

The section, at the bridge (Fig. 17) above referred to, displays sandstones at water-level somewhat cross-bedded and carrying scattered pebbles and small blocks. I measured one granitic fragment 16 inches long.

On the south side of the Rio Negro along the road going eastward towards São Bento yellow tillite beds with intercalated dark shales contain many granitic boulders. A cobble eight inches in diameter showed good striation. The boulders range from two to three feet

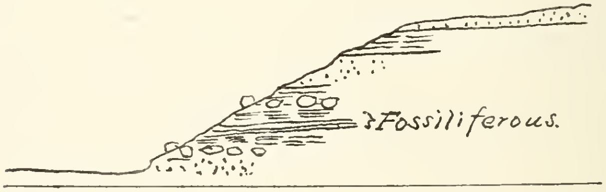

Fig. 18.— Section of fossiliferous Permian marine shales between boulder-beds near Rio Negro.

in diameter, all in the yellow sandy tillite, with very few small pebbles, arguing for floating ice. A few kilometers along this road eastward from the bridge where a small stream has cut a well-defined valley in its descent to the Rio Negro, Dr. Oliveira found a marine fauna in black shales intercalated between two boulder-beds of the tillite series (Fig. 18). I refer to this bed and its apparent significance elsewhere.

A few kilometers farther east by south along this road a new cut near the small Rio da Vida nova displayed the shales and tillite beds (Plates 23 and 24), at horizons closely corresponding to the beds above

the marine fossiliferous zone. In this locality the shales also carry boulders and stones. That in the view being a boulder of gneiss about twenty inches in the diameter on the exposed section. Below the middle of the part of the bed shown in the plate there is a thin, well-defined layer one and a half inches thick of the yellow material which is called tillite in this paper. The layer consists of sand grains and earth particles with coarse angular grains ranging to the size of very small pebbles, and by its mode of occurrence is strongly suggestive of deposition, like that of the stones included in the shales, by floating ice, probably the manner in which the thicker beds of the same character were laid down in this section. The shales part with a thin splintery fracture subparallel to the bedding.

The overlying tillite bed is composed mainly of fine earthy material with coarse sand grains, and scattered pebbles; some of these latter display glacial striae. Among the types of rock was noticed one example of a coarse-grained diabase. This bed is about eight feet (2.5 meters) thick, and is remarkable for the almost perfect development of the bale structure so characteristic of some varieties of igneous rock. No trace of stratification was detected within the limits of the stratum.

About two Brazilian leagues from Rio Negro and further to the south and east along this same road, the Ribeira das Rutes, a small tributary of the south bank of the Rio Negro, has cut a gorge with a fall at its head in the blue unweathered tillite. This rock contains rather abundant stones in a matrix of clay beset with small subangular fragments of rock and coarse sand grains.

North of the fossil locality above mentioned and lower down along the course of the Rio da Vida Nova the river road intersects a water-worn conglomerate from six inches to two feet thick with pebbles of sandstone and rocks resembling the formation in which it is intercalated. It is overlain and underlain by sandstones of the same yellowish hue as the tillite beds, resembling a solidified loess.

Section from Rio Negro Southward to the Top of the Series.— South of Rio Negro and upward in the series, sandstones and shales are crossed by the Lages road as far as the Rio Laurenço, at 1,500 mule paces north of which I saw a large granite block four feet long lying on the outcrop of bluish shales. On the south bank of the Rio Laurenço a thick sandstone formation comes in. Scattered pebbles and a few boulders are seen along the same road farther south towards Sepultura. Beyond this point southward and higher in the section no good evidence of embedded pebbles was seen.

The Tuberão Valley Section.— The Permian beds at Orleans and near Minas in the upper valley of the Rio Tuberão are better known than any section of the Palaeozoic north of Rio Grande do Sul. Not only have the coal beds in that hydrographic basin been reported upon at different times by a number of foreign mining engineers but

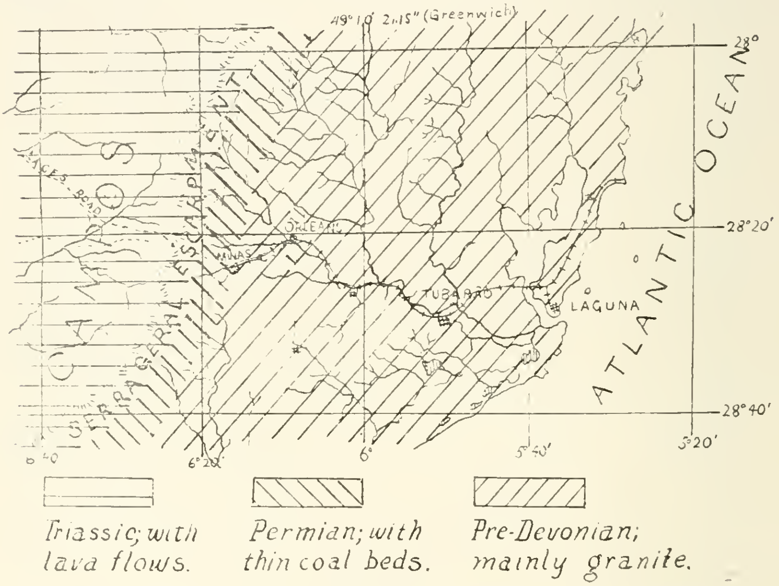

Fig. 19.— Sketch map of the Minas-Orleans district in the Tuberão Valley, Santa Catharina.

the region has been very thoroughly explored by Brazilian geologists and recently the staff of the Coal Commission under the directorship of Dr. I. C. White has made a still more detailed report upon the geological structure and the nature of the strata of this part of the field. According to the terminology of Dr. White's Report this section from the granite basement to the top of the Serra Geral trap plateau comprises the following formations named in descending sequence: —

Triassic
- São Bento series
  - Serra Geral eruptives
  - São Bento sandstone
  - Rio do Rasto red beds

Permian
    Passa dois series
        Rocinha limestone
        Estrada nova beds
        Iraty black shale
    Rio Tuberão series
        Rio Bonito beds
        Orleans conglomerate

In this report we are concerned mainly with the beds grouped in the above section under the head of the Orleans conglomerate at the base of the Permian section in southeastern Santa Catharina.

Dr. White (1908, p. 51) describes the Orleans conglomerate as follows: —

"Resting upon these lower sandstones and shales often in apparent conformity, we find a coarse conglomerate which is well exposed in the town of Orleans, Santa Catharina, from which locality it has been named. It contains boulders of granite, quartzite, and other hard rocks, some of which are 20 to 25 centimeters in diameter. The same formation is frequently visible along the Rio Tuberão between Minas and 2 kilometers below. The bore hole put down near Minas station began near the top of this rock and passed through the same at a depth of 5.35 meters. In Rio Grande do Sul large granite blocks are frequently found at this horizon, as well as at many points in Paraná and the adjoining region of Santa Catharina, where several localities, near Rio Negro, 10 kilometers from any outcrop of granite, exhibit granite boulders in vast numbers up to 3 meters in diameter, all embedded in a fine and apparently unstratified gray muddy sediment. A very coarse deposit with large rounded boulders of granite, quartzite, sandstone, silicified wood, etc., may also be seen resting unconformably upon Devonian shales at Ponta Grossa, and other localities in that region. This deposit appears to correspond closely to the Dwyka conglomerate of South Africa, and most probably, like it, is of glacial origin, although no scratches were observed upon the boulders in question." Between the conglomerate and the base there usually intervenes a few meters of sandstones and shales. In the boring at Minas, these beds together with the conglomerate are said to have a thickness of twenty-seven meters. On the road from Lages to Florianopolis farther north the total thickness is from 150 to 160 meters (White, *loc. cit.*, p. 49). At Xarqueadas, in Rio Grande do Sul near the right bank of the Rio Jacuhy a boring was put down in

which a conglomerate 1.80 meters thick is recorded as resting on the granite floor (White, *loc. cit.*, p. 43). Eighteen kilometers southward from Xarqueadas in another boring the Orleans conglomerate is reported with large blocks of granite and with a thickness of 16.16 meters, resting directly on the granite.

In the exposures reported between Florianopolis and Lages and

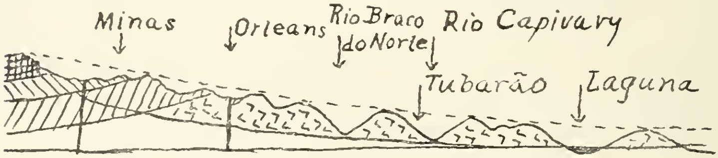

Fig. 20.— Section of the Minas-Orleans basin.

between Lages and Blumenau in Santa Catharina, there is described among the beds beneath the conglomerate horizon "a very hard fine grained grayish white whetstone grit" in layers eight to twenty centimeters in thickness. These layers it is also stated gave the name Navalha to the village on the Blumenau-Lages road near which locality they were once quarried for whetstones. Similar beds are likewise mentioned in the same report as resting with a few meters thickness on the granite near Suspiro in Rio Grande do Sul and also along the Rio Trombudo where crossed by the Blumenau-Lages road. Attention may here be called to the fine-grained compact white siliceous rock which underlies the boulder-beds on the right hand bank of the Jaguaricatu along the railroad between Sengéns and São Pedro de Itararé in northeastern Paraná described on page 62; fragments of this rock appear to be abundantly distributed in the shales and sandstone of São Paulo often with glacial scratches.

I have little more than details of structure and the conclusions based thereon to add to Dr. White's account of the Permian conglomerates of the Orleans basin. This basin (Fig. 21) is a downfaulted outlier of the Permian area. The boundary fault, on the western margin of the basin, brings the sediments against a basic dike whose shattered condition suggests that the faulting occurred after the intrusion of the dike. A short distance west of this broad dike is a narrow basic dike somewhat faulted within its mass. I observed two nearly vertical slickensided surfaces striking nearly northwest southeast on which the slickensides pitch to the southeast on the eastern fault at angles between twenty-five and thirty degrees and

indicate, by the detailed structure of the surfaces, that the downthrow was on the northeast side in accordance with the structure of the Orleans basin. It is evident therefore that repetitive small faults occasion the base of the Permian section in this district.

The conglomerates are exposed along the river banks below the

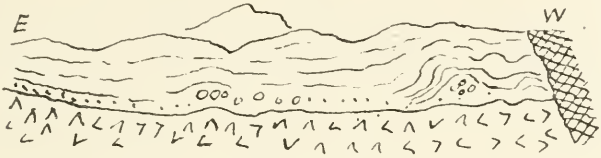

Fig. 21.— Section of beds in Orleans basin, south bank of the Rio Tuberão. The rock on west is a broad trap dike.

town and are best shown on the north bank under the railroad track, (Fig. 22). There is here a water laid conglomerate mainly of granite pebbles with a few quartzite and quartz pebbles. The conglomerate is overlain by cross-bedded grits, the cross-bedding dipping to the north and northwest as if deposited by currents of water flowing at least locally in that direction. The pebbles in the conglomerate bed, mostly three inches in diameter, sometimes attain five inches, and are embedded in a paste of granitic detritus. The subrounded shape of the pebbles indicates no distant journey and their lithological character betokens a derivation from the granitic terrane which immediately underlies the local Permian section. (See Plate 25.)

Another exposure of the conglomerate about 90 meters down stream from the preceding exposure presents the cross-section of a north-south ridge of coarse pebbles enveloped in cross-bedded sandstones. In a layer of conglomerate varying from 0 to 60 cm. in thickness the cobbles attain a diameter of 20 cm. The ridge-like deposit, so suggestive of a buried esker, is apparently continued across the river on the south bank of which there is a ridge-like exposure of conglomerate also covered by sandstones. A few yards east of the ridge on the north bank there is exposed a bed with rounded granite pebbles scattered through a sandstone matrix as if dropped by floating ice.

Fig. 22.— Esker-like ridge of conglomerate in lower Permian beds; near Orleans, Sta. Catharina.

All of the strata below the railroad track are essentially devoid of decomposition evidently because of the geologically recent lowering of the bed of the river. While the assemblage of water deposited conglomerates in this section are entirely consistent with neighboring glacial conditions there is no true tillite in the lower part of the section and while the ridge may be an esker the evidence is not conclusive. It is possible to regard the narrow belt of conglomerates as deposited in the channel of an aggrading stream which in its later stages of deposition laid down the cross-bedded enveloping sandstones.

As the Orleans section by no means affords a typical exposure of the tillite beds the name seems inappropriate for the glacial conglomerates

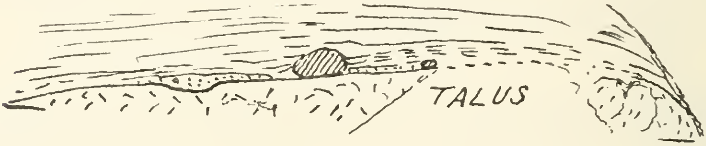

Fig. 23 — Basal boulder in Permian shales, resting on granite, near Minas, Sta. Catharina.

and Dr. White (Woodworth, 1910, p. 779) having kindly coincided in the matter the name Jaguaricatu has been substituted for this horizon because of the splendid exposures of tillite along the banks of this river in railway cuts in northeastern Paraná.[1]

In the exposed section of base of the main area at Minas no conglomerates were encountered. A few scattered granite and quartzite pebbles occur in sandy beds but without striae or flattened sides or crushed and snubbed ends indicative of glacial action. About 2.4 kms. below the railway station in a railway cut the basal Permian shales may be seen resting on the Pre-Devonian granites. On this ancient surface reposes a boulder of granite about three feet (1 meter) in diameter covered by the shales. Some small grooves or channels in the granite are filled with a gravelly sandstone. No traces of a glaciated floor were discernible.

It remains to characterize the glacial features of the above described localities as a whole and to draw from the evidence now in hand such conclusions as appear tenable.

There can be no doubt as to the glacial origin of the massive tillite beds in Paraná and their likeness to the tillites of Permian age in India, Australia, and South Africa. The massive aggregation in

northeastern Paraná is highly suggestive of moraines laid down by land ice; but other sections in São Paulo and to the south and west in Paraná are equally clear as to their deposition by floating ice at times at any rate in the sea as the presence of marine fossiliferous marine shales in Paraná plainly show.

More particular problems arising in the study of these glacial deposits are discussed under separate headings.

The Striated Pebbles. — So far as present knowledge goes, striated surfaces have not been found on the large boulders and block erratics in south Brazil, but such ice-worn surfaces are frequently met with on pebbles and fragments of rock ranging from the size of a hen's egg to that of a man's head. In almost every exposure of conglomerate whose pebbles fail to display the well-rounded contour of water-wear a few striated pebbles may be found after a few minutes search; yet of these sections I saw none in which all the pebbles and fragments were striated. On the whole the proportion of striated pebbles in the tillite beds is about as large as it is in the granitic till of the glacial deposits of New England, but glaciated stones are certainly not so abundant in any given mass as they are in the stony blue clays of many localities in the Pleistocene deposits of, for instance, portions of the Wisconsin moraines of the state of New York.

The absence or apparent absence of striae from the larger blocks and boulders is quite in keeping with the distribution of striae in the Pleistocene of many districts and has little significance in the arguments for or against glacial action, though in the case of the Brazilian deposits striae were not earlier noted perhaps because attention was given more to the blocks of striking size than to an examination of the worn surfaces of small fragments of transported rock.

Broken up striated Rock-floors.— As the glaciation and consequent striation of the indurated terrane over which the ice moves proceeds, the rock-floor particularly at the upstream edges of small declivities in the rock-surface breaks away, so as to produce angular fragments with one flat well-striated surface — that of the original floor. Such pieces of rock may subsequently be striated over all their new fractured surfaces but will for short journeys tend to preserve their features. Thus the striated stone shown in Plate **27**, the first striated fragment found in Paraná, presents all the ear-marks on its well worn and striated side of a piece of old rock-floor even to the chatter-marks in the broader and deeper groove; while on the reverse, where there are two intersecting warped surfaces one is slightly scratched, and the other is a much more recent fracture, still of a date anterior to the final embedding of the pebble.

Although no glaciated rock-floor has yet been found in south Brazil, pebbles of the type above described point to the one-time existence of such a rock-floor though it is no longer to be seen. In this particular instance that of a pebble from the tillite beds on the Jaguaricatu the rock is a reddish brown [1] fine compact argillaceous sandstone, with a perceptible clayey odor when breathed on, and carrying minute scales of muscovite.

Crushed and Blunted Rock Fragments.— Striated pebbles or rock fragments with or without flattened sides or "soles" are commonly regarded as the most characteristic molar constituents of moraines directly due to glacial action; but there is another type of pebble in ice-laid moraines which is equally peculiar to the process of erosion and transportation; that is the pebble with blunted and snubbed ends with or without striae. This kind of pebble is usually rather elongate and oftener displays its fractured and splintered surface at that extremity which has the smallest cross-section. Such fragments are not uncommon in the glacial drift of North America and I have found them in the tillite of Paraná in the beds along the Rio Jaguaricatu. One example quite characteristic in every feature is illustrated in Plate **27**, fig. 3.

The small intersecting surfaces which give rise to the beveled appearance of the subpointed portion of the periphery of this rock fragment are surfaces of fractures produced by the riving off of spalls of the rock through pressure applied at points along the major perimeter of the pebble. In the case of this pebble, there are three such larger fracture surfaces and each of the later fractures was followed by a repetition of the pressure at approximately the same point so as to force a smaller spall with a subconchoidal fracture. At some stage in the same process after the intermediate surface was produced by fracture, the wedge-shaped point of the pebble was broken squarely off. All of this fracturing was accomplished previous to the final embedding of the pebble in the tillite bed. Owing to the concavity of the fracture surfaces, they escaped striation, yet some slight scratching took place on the two larger surfaces.

Such fracturing is apparently due to the forcing of pebbles against the bed rock or against other rock fragments in the ice or by their being caught under boulders so as to have a great weight of ice concentrated upon them when they in turn are in contact with the bed rock.

[1] The color of the dry isolated rock is close to Orange 130, Klincksieck et Valette: Côde des coleurs (Paris, 1908).

Where this type of pebble occurs on the surface of the ground at the present day as it does in the glaciated regions of eastern North America it might possibly be interpreted as owing its conchoidal fractures to the work of aboriginal man, but when firmly embedded in the glacial till of that district or in the tillite beds of Brazil no one would presume to connect it causally with human art. These crushed and bruised rock fragments with their sides well striated are common in south Brazil and along with other striated pebbles argue for the crushing, bruising action of a thick body of ice such as a glacier would afford. Even where stones of this type of contour occur isolated in fine shales into which they have been dropped from floating ice, the evidence as to their original handling by glacial action is equally good.

Classification of Lithified Glacial Deposits and Derived Sediments.— The lithological classification of sediments takes no account of genesis, its names, somewhat more carefully defined than in common usage, express ideas concerning the size of constituent particles, as in the terms conglomerate and sandstone; or designate vaguely a mode of fracture, as in shale with an understood composition of particles too small to be distinguished by the unaided eye. This simple primitive classification embraces all lithified glacial deposits when used with proper qualifying terms. The glacial deposits, so far identified, have given rise to two independent terms, boulder-bed and tillite, the first of which is conveniently vague, except for its reference to boulders, while the second covers a wide range of commingled rock fragments and particles having this in common that they were deposited by the agency of glacial ice. The study of modern glacial deposits would lead us to expect among ancient glacial deposits the lithified counterpart of each product of glacial action and the glacio-natant waters. Tillite, as consolidated till, would naturally be applied to all unstratified, unassorted deposits due to the direct agency of a glacier. The term thus is applicable to the rock of fossil moraines whether frontal, or ground-moraine, and to fossil drumlins. These varieties of tillite, since they are distinguished by topographic form, will not in the nature of the case take petrographic designations. The same remark applies to the assorted glacial gravels and sands forming the group of kames, eskers, and proglacial deltas, or gravel- and sand-plains. For their petrographic designation there is no distinctive term correlated with till and tillite. The coarser deposits are included in the conglomerates and the finer among the sandstones. The glacial rock-flours or clays, normally unweathered, finely divided clastic materials of complex mineralogical composition, often feldspa-

thic, should be sufficiently distinct from true clays to receive a specific name in the system of classification; but none occurs for modern deposits of this type in accepted usage. Such lithified glacial rock-flours may be called *pelodite* from πηλώδης, ες (πηλος, εἶδος), *ite, clay-like rock,* in reference to the fact that these rocks often clay-like or shaly in texture and structure, when first formed may differ widely from typical clay in the very small amount of kaolin which they contain. Pelodite is to be differentiated from pelite also by its included glacial pebbles.

Closely associated with modern glacial deposits though distinct in origin and often very differently distributed is the fine mainly eolian deposit known as loess frequently derived from glacial moraines through their deflation by winds. Some of the finer sediments of the Brazilian Permian resembling clays seem to be of this origin. Such lithified deposits of loess may in analogy with tillite be called *loessite.*

With these preliminary statements it is to be presumed that the following tabulated classification of glacial deposits will need no further explanation.

Modern unconsolidated deposits.	*Divisions depending on form.*	*Ancient lithified deposits.*
Till		Tillite.
Boulder-clay		do.
	Moraine, frontal, ground-. drumlins	
Glacial gravels		Glacial conglomerates.
	Eskers, kames; glacial deltas.	
Glacial sands	Deltas and plains	Sandstones.
Glacial clays		Pelodite.
Loess		Loessite.

Classification of the Glacial Deposits of South Brazil.— With the above simple classification in mind, it appears that the Permian moraines of south Brazil presents several facies of a glacial series, both stratified and unstratified.

In the tillite group must be placed the typical blue boulder-clays of the Rio Jaguaricatu section, the gravelly beds with large angular blocks, beds presumably of the ground-moraine or subglacial type. Unfortunately the limited exposures in the deeply forested river valley do not permit of a determination of the topography of these ancient beds of drift. In somewhat sharp contrast with the analogue

of true boulder-clays is the earthy type of tillite seen in the vicinity of Rio Negro. This I believe was deposited by floating ice in a shallow sea without stratification.

There are many beds composed of small rock particles embedded in an argillaceous ground-mass carrying only occasional striated stones which present some of the characters of flood deposits but which by reason of their glacial features it is to be presumed are tillite. In their yellow weathered state, their diagnosis is made with difficulty. They grade into "mealy" yellow sandstones.

The group of stratified gravels appears to be represented in the Orleans basin by the small ridge of conglomerate whose cross-section and horizontal extension recalls the form of an esker. The other occurrences of conglomerates as at Ponta Grossa do not show topographic features which enables one to distinguish them from gravels of non-glacial origin.

The dark colored shales in the Permian series, on the whole much less developed in thickness than the coarse sediments, have not been studied with reference to their glacial derivation. Where they contain marine fossils it is to be presumed that they have been worked over and any original glacial characteristic has been lost. Some of the fine clayey beds of sandy aspect which behave like loess in their weathered condition I suspect were originally loess, but this determination is difficult to make.

The large content of clay in the tillite beds of Jaguaricatu and Conchas on the Tibagy is not consonant with the derivation of these beds from the granites and gneisses of the present Serra do Mar region since such rocks under the direct attack of glaciation would produce predominantly gravelly and sandy beds with a minimum of clay or rock-flour of an argillaceous character. For this reason I am disposed to regard these clayey tills as worked over from the underlying Devonian shales and from the slates of the Pre-Cambrian series. This makes it possible to suppose that much of the material did not come from any great distance to the east of the Serra do Mar.

The tillite beds which approach nearest in their lithological characters to a solidified boulder-clay appear when fresh of a bluish color somewhat darker than the hue of the glacial brick clays of many parts of the United States of America. On exposure the rock weathers to a light brown or yellowish brown color often with streaks of reddish iron oxide.

This rock joints irregularly; frequently its fracture assumes a curving plate-like structure tending toward the dome structure and

actually attaining that of spherical separation, thus producing the bales shown in the Rio Negro section, characteristic of many weathering basalts, an effect coupled with the want of definite stratification within the stratum.

Once the tillite beds underlying sandstones are reached by dissecting streams or rivers, the overlying strata widen out with steep cliffs, the small streams falling over these rocks have falls, and, owing to the ready removal of the tillite and the growth of the main valley in this section, the side streams present the appearance of hung up valleys.

Age of the Boulder-Beds.— As commonly stated on the authority of Dr. Derby the boulder-bearing deposits are to be regarded as the equivalent of the Upper Carbonic or Permian glacial period now recognized in India, Australia, and South Africa. This Permian age of the beds in Brazil was accepted by Professor Branner in his Geologia elementar (Rio de Janeiro and São Paulo, 1906), and still more recently by Dr. I. C. White in his Report on the Brazilian coal field. In the same monograph, Mr. David White presents the most complete description and analysis of the flora of the south Brazilian field yet published. From this report it appears that the flora succeeding the conglomerates on the south in Santa Catharina are of the Lower Gondwana type which immediately succeeds the glacial beds in India and elsewhere in the eastern hemisphere. Dr. David White correlates the Jaguaricatu beds [Orleans conglomerate] and associated sandstones and shales of Dr. I. C. White with the Talchir beds of India, the Dwyka conglomerate of South Africa, and the basal conglomerate of the Permian series of Argentina.

Divisibility of the Glacial Beds.— The question is naturally asked whether there was one or more than one episode of glaciation or ice-action in southern Brazil. The facts concerning the distribution of conglomerates in this field are as yet too little known to enable one to give a satisfactory statement in reply to such a question. The localization of the typical tillite beds near the base of the series so suggestive of local contributions of débris complicates the question. If the conglomerate beneath the whitish sandstone at Serrinha Station with its glaciated fragment be of Permian age and pass, as it appears to, beneath the boulder-bearing beds exposed westward and southwards towards Lapa, then in that section there are evidences of two epochs of ice-action separated by the deposition of the sandstone beds which form the walls of the gorge of the Iguassú.

The tendency of the boulders to display themselves in a marked manner in certain zones often only a few feet apart is evidently a

result of deposition from floating ice and such distribution can not be depended upon as a basis for discussing advances and recessions of glaciers. It can only be said here that the evidence seen points to the existence of two horizons on which ice-action directly or indirectly arising from glaciation appears to be demanded.

It would seem from a comparison of the partial sections visited in the course of this Expedition that the boulder-beds are not persistently parallel formations, that the more typical tillite of one district may pass by gradation or intercalation of deposits into contemporaneous waterworn gravels or sands, now conglomerates and sandstones in another district along the strike of the beds. Thus in the sections along the Jaguaricatu in northeastern Paraná, the tillite with large angular blocks surmounts with few intervening feet of beds the white fine sandstone which appears to be a fairly persistent basal and preglacial member of the Permian series. In the latitude of Ponta Grossa the tillite appears at a much higher horizon, the apparent place of the Jaguaricatu tillite formation being taken by beds of waterworn pebbles. Again in the gorge of the Iguassú at Serrinha Station, if the beds be truly of Permo-Carbonic age at this horizon, a conglomerate with striated pebbles occupies an inferior position near the base of the series. At Orleans, yet further south, the tillite is replaced in the section by waterworn conglomerates possibly, though not certainly, laid down in the presence of ice in the manner of eskers.

This alternation from point to point along the present roughly meridional line of exposures, thus described of deposits approximately at the same level in the series, and probably more or less contemporaneous, finds a parallel in the existing deposits of glacial origin within the glaciated areas of Europe and North America. In traversing the glaciated region of the latter area we pass from north to south over belts of till with alternating strips of waterworn gravels and coarse sands and clays. In this particular case the deposits are successively newer in the direction in which the ice retreated, *i. e.* towards the north. We encounter another mode of deposition of alternating accumulations of ice-laid and water-laid drift, however, in which the likeness to the Brazilian distribution, so far as it is at present known, is equally close. That is where glaciers coming down either as distinct valley glaciers or as outflowing tongues from a central ice-cap reach the coastal plain or sea-floor at the base of a highland region so as to deposit till in the vicinity of the paths by which they reach the low grounds while the intervening areas receive only the waterworn débris. In south Brazil, what seems to be evi-

dence of an eastern origin for the glacial débris points to this latter mode of deposition rather than to the first above outlined.

Our knowledge of the Permian of south Brazil is limited to the narrow belt from which the overlying supposed Triassic beds have disappeared by erosion. The Permian is not represented as reappearing on the western flank of the broad shallow syncline which subtends the structure as far west as Cuyubá in Matto Grosso but it is probable that the Permian extends far beneath the Triassic cover.

Boulder-Beds of the Argentine Republic.— The brief references of Bodenbender (1895) to the occurrence of boulder-bearing beds beneath the Gondwana flora in the provinces of San Luis and Mendoza in central Argentina may be presumed, though this geologist does not infer their glacial origin, to indicate an extension of the Brazilian Permian geographic conditions to the south and west quite to the base of the Andes, thus practically carrying the peculiar geographic and climatic features of the Permian across the continent of the southern hemisphere from one shore of the Pacific Ocean to the other. Details concerning the agency concerned in the transportation of these Argentine deposits is as yet lacking and until the precise facts on this point are known it would be presumptuous to draw further conclusions from the deposits concerning the glacial problems of the South American Permian.

Boulder-Beds of the Falkland Islands.— Mr. Thorre G. Halle (1911, p. 115–229) reports the existence of a boulder-bed and typical tillite with striated flat-faced pebbles at the base of a Permo-Carboniferous series on East Falkland Island. Higher up in the section occur Glossopteris, Gangamopteris, Phyllotheca and other members of the Gondwana flora.

The occurrence of glacial deposits in south Brazil and on the Falkland Islands carries with it the presumption that the boulder-beds beneath a Gondwana flora in Argentina are also glacial in origin whether or not they now show striae, which latter may yet be found on the small rock fragments.

Gondwana-land. Did it include Paraná-land? — Palaeogeographers relying largely upon the distribution of the fossil genera Glossopteris, Gangamopteris, and their plant allies of Permo-Carboniferous times with the associated glacial boulder-beds have gradually extended the name Gondwana-land from its original application to the Indian South African area so as to include the South American tracts in which traces of the Gondwana flora occur. To a certain extent the name has thus become designative of a set of geographical conditions

rather than a definitely determined continental tract of such vast extent. Some geologist of the distant future viewing the embedded traces of the Pleistocene glacial period of northwestern Europe and northeastern North America might with almost equal assuredness point out the existence of a vast continent embracing these areas and the included basin of the existing North Atlantic Ocean. The geographical conditions peculiar to Gondwana-land are found in India, Australia, and in South America from the Falkland Islands to the northern borders of the state of São Paulo. Representatives of this flora apparently of later date occur as far north as the Mexican state of Oaxaca, there with plants of a Triassic facies, Williamsonia, Zamites, Otozamites, etc. (Wieland, 1909, p. 441–442). For the purpose of designating the larger tracts in which this Permian flora and the glacial conditions occur, Gondwana-land has thus lost its original limited meaning. The south Brazilian field with its boulder-beds and later Triassic trap sheets constitute a well-defined geological province to-day for which the name Paraná-land is quite appropriate. It is to be presumed that Paraná-land was conterminous with land southward over Argentina and thence to the continental island group of the Falklands. All three of these Gondwana areas lie within that of the existing continental block.

The question of the connection of South America with Africa in Permo-Carboniferous times may be stated in other terms in a more general form to be that of the origin and history of the Atlantic Ocean basin, which Suess has discussed in no uncertain way. The fact that there is no recognizable trace of the Atlantic Ocean along its existing borders in early Triassic times, except for a narrow sea marginal to the Mediterranean tract, and the fact that the Atlantic is a narrow and not deep sea are quite consistent with the hypothesis of the origin of this depression since Lower Triassic times. Certainly the assumption of an Atlantic trough in Pre-Triassic times having anything like the present extent of that basin must be abandoned as being without sufficient geological evidence. Viewed in the light of Suess's masterful generalization of the geology of the Atlantic shores, we find no trace of the South Atlantic Ocean during the Carbonic period until the possible marine episode of the Permian epoch in South Africa [1] and in south Brazil if indeed these waters penetrated these continents from the Atlantic basin. In Brazil it is more probable that the sea invaded the state of Paraná from the west. Without

[1] Halle notes the report by Schroeder of marine fossils above the Dwyka conglomerate in German southwest Africa. *Op. cit.* p. 203.

further details concerning the African Permian sea it is possible to admit a shallow sea in the Atlantic area as far north in that district as the southern tropic, but this at a later stage than the epoch of principal glaciation in Africa. Both in Africa and South America, the marine beds of the Permian demand land near sea-level immediately before and after the invasion by the sea. Little else can at present be argued from their occurrence.

The volcanic islands which stake out the mesial line of the Atlantic and its connection with the Arctic Ocean hug the shores of Europe and Africa rather than those of the Americas. Since those volcanoes whose substructure is known are associated with crustal displacement involving either horizontal or vertical motion or both and particularly the latter mode of derangement, it is probable that we see in these islands the indirect evidences of a geologically recent movement of the Atlantic bottom which we know from Iceland was well under way in Miocene times. Along the shores of North and South America which trend northeast and southwest we find traces of downsinking of the land in Cretaceous times. In the North Atlantic region, the Pan-Appalachian mountain-chain extending from the dislocated structures of the Rocky Mountains across the southern United States to the coast in Newfoundland can be traced north of the Alps in Europe into Asia but is interrupted in the Mississippi embayment and by the North Atlantic basin which cuts across the folded structures as if they had sunk to form the present ocean floor. These and other indicated changes of depth and outline of the Atlantic province make it incredible that in Permian times the basin had much of its present length, breadth, and depth. We may conclude therefore that the geologist is free to converge the coasts of Africa and South America in Permian and earlier Carboniferous time as closely as any biological facts and geological evidences of land may demand for their explanation.

In south Brazil all the known facts from the Atlantic border demand an extension of land beyond the present coast in late Palaeozoic time, but how far towards the coast of Africa we can not say. The discovery of the Gondwana flora in the Falkland Islands makes it possible to effect the distribution of these plants from Australia into South America by way of the Antarctic continent. Possibly Africa also received its population by this route or more likely from India. The revealing of the geology of the Antarctic continent receives from this state of the problem of Gondwana-land a renewed interest.

The Permian Glacial Problem.— In the foregoing account of the

Permian boulder-beds of Brazil I have set forth the evidence for the existence of glacial discharge of débris at or near sea-level. The occurrence of boulder-beds, presumably likewise of glacial origin, in central Argentina is supported by the finding of tillite in Permian beds on the Falkland Islands. These occurrences practically complete the evidence that the Permian glacial traces occur on all lands outside of the Antarctic circle in the Southern Hemisphere from shore to shore of the Pacific Ocean. In South America the evidences exist from the tropic of Capricorn southward to 52° S. L. They occur in South Africa coextensive with the sediments of the time. In Australia they occur over a vast area in the eastern part of that continent and in Tasmania. It is now apparent that no shift of the polar axis in Permian time will bring these evidences of glaciation into a better circumpolar distribution than they now display.[1] Thus those hypotheses which attempt to account for Permian glaciation by a shift of the earth's axis of rotation have not been called for by any facts which we now possess. The discovery of tillite in the latitude of 52° S. diminishes the difficulty of the climatic problem by removing the supposition that the glaciation was dominantly a subtropical affair. The general absence of existing land in the Southern Hemisphere in the latitude of the Falkland Islands probably accounts for the present lack of signs of Permian glaciation in high latitudes. The Antarctic continent is too little known as yet to premise what evidences future explorations may bring forth. The facts upon which the Permian glacial period rest still come largely from the Southern Hemisphere, where at present the ratio of area of land to sea is so small.

In the Northern Hemisphere the Permian glacial deposits remain most typically developed and best known in the subtropical region of India, in the Salt Range and Talchir districts. But traces of ice-action in high latitudes are not wanting and are coming continually to light with the more critical diagnosis of the conglomerates of the late Palaeozoic terranes. The Permian breccias of England regarded by Ramsay as of glacial origin as early as 1855 appear to be now accepted as such by English geologists.

These traces occur in Latitude 53 N. A. Julien supposes the coarse breccias of the Carboniferous in France to be of glacial origin, and Kalkowsky attributes to glacial action a pebbly shale among the Carboniferous rocks of the Frankenwald. These occurrences in Europe pointing to some kind of ice-action if not in every case to the

[1] Halle draws the same obvious conclusion from his discovery of the tillite on the Falkland Islands.

existence of glaciers demonstrate the wide distribution of the climatic conditions producing Permian glaciation and where the traces of ice-action exist in horizons below the Permian show that the glaciation of that period was induced by causes not suddenly brought into play.

In North America in latitude 42° S., Messrs. R. W. Sayles and L. A. Laforge have called attention to a remarkable breccia at the top of the Roxbury conglomerate south of Boston in which many of the peculiarities of glacial till occur, including a few striated pebbles. The precise position in the time scale of this bed is not known from contained fossils in the local series but its relations to the Narragansett coal field on the south make it presumable that the beds are Permian. In Oklahoma in about latitude 35° S. erratic blocks occur in a shale of Subcarboniferous age. The striae on these transported stones are of post-depositional origin due to rock motion but the transportation of the boulders remains unexplained except by floating ice. The evidence from North America, as yet meagre, points to the same conclusion as that derived from the distribution of breccias and conglomerates of Carboniferous and Permian age in Europe. So far as the facts from North America go, local glaciers are the most that at present can be postulated.

What combination of geographic with atmospheric conditions brought about Permian or even Pleistocene glaciation we do not know with any degree of certainty. All our hypotheses of glaciation postulate glaciers and ice-sheets engendered from the fall of snow. It is possible, though not now seemingly probable, that under the peculiar recurrence of hailstorms which are, in the existing regime unusual forms of precipitation, masses of ice might accumulate in tropical and subtropical areas where snow never falls.

Hail and allied forms of frozen rain-drops enter more largely into glaciers in existing mountains than is perhaps commonly recognized. Kaemtz (1845, p. 380–382) gives several citations to show that hail frequently falls on the Swiss Alps. It is probable that no small amount of hail enters into the structure of Swiss glaciers. De Saussure states that during a stay of thirteen days on the Col de Geant at an elevation of 3,428 meters he was struck with the frequency of hail and sleet which he observed eleven times. Balmont experienced a shower of hail during the night that he passed on the summit of Mont Blanc and Paccard found much hail beneath the snow with which the summit is covered.

Edward Whymper (1892, p. 164 *et seq.*) describes frequent falls of hail within the region of glaciers on the mountains of Ecuador. When

nearly 16,000 feet high on the slope of Sincholagua on Feb. 23, 1869, a furious hailstorm took place followed after a lull by a fall of snow mixed with hail which gave way in turn to a thick fall of large flakes of snow. There was a glacier at this time on the mountain. Again in describing his ascent of Antisana on March 9, 1869, he states that at the height of 15,984 feet at the top of a moraine on the right bank of the glacier a fierce hailstorm occurred about 4 P. M. and snow fell heavily afterward.

Charles Darwin (1845, p. 115–116, or 1887, p. 115–116) describes a remarkable fall of hail in Argentina near the foot of the Sierra Tapalguem between Bahia Blanca and Buenos Aires on the night of Sept. 15–16, 1833. The hailstones were said to have been as large as apples. The same distinguished naturalist cites the account of the Jesuit Brobritzhoffer who states that in the region much further north hail fell of an enormous size and killed vast numbers of cattle, hence on this account the Indians called the place Lalegraicavalca, meaning the "little white things." Darwin also quotes Dr. Malcolmson to the effect that this observer witnessed in India in 1831 a hailstorm which killed large birds and injured cattle. These stones were flat; one was ten inches in circumference, and another weighed two ounces. They ploughed up a gravel walk like musket balls, and passed through glass-windows, making round holes but not cracking them.

Sir Joseph D. Hooker (1854, **1**, p. 405) gives a personal account of a hailstorm which took place on the 20th of March, 1849, on the south slopes of the Himalayas. "A violent storm from the southwest occurred at noon, with hail half an inch across and upwards, formed of cones with truncated apices and convex bases; these cones were aggregated together with their bases outwards. The large masses were followed by a shower of the separate conical pieces, and that by a heavy rain. On the mountain this storm was most severe, the stones lay at Darjiling for seven days, congealed into masses of ice several feet long and a foot thick in sheltered places; at Purneah, fifty miles south, stones one and a half inches across fell, probably as whole spheres."

According to Lieut.-Commander Gorringe, U. S. N., (1873, p. 331) the city of Rio de Janeiro was visited by a storm with a heavy fall of rain and hailstones on October 10, 1864. The hailstones were as large as pigeon's eggs. "Branches of trees were broken and twisted off, and the foliage destroyed by the hail, which poured down in such quantities that piles of it remained at the corners of the streets until the afternoon of the following day."

Thomas Russell (1895, p. 98–100) gives a few statistics regarding the falls of hail as follows: — Hail falls during thunderstorms in summer and during the hottest part of the day. It rarely forms layers six inches thick. On Aug. 13, 1851. hail fell in New Hampshire to the depth of 4 inches. On July 24, 1818, it fell on the Orkney Islands to the depth of 16 inches, on August 17, 1830, in Mexico City, to the depth of 16 inches. In the Yellowstone valley in Montana a fall of 14 inches has been recorded . . . . Hail is more common at 15,000 feet than at sea-level, it forms at elevations from 5,000 to 16,000 feet; the greatest size of hailstones is found below 5,000 feet. It falls most frequently on the lee side of rising ground . . . . There are on the average fifteen hail storms a year in France, five in Germany, and three in Russia.

In the Antarctic region hail now falls but rarely. Commodore Wilkes alone reports two instances. Fog there gives rise to some crusts of ice. (Fricker, 1900, p. 244).

Alfred R. Wallace (1892, p. 299) states that he had good authority for hail having once fallen on the upper Amazon at a place only three degrees south of the equator and about 200 feet above the level of the sea. Humboldt (1852, **2**, p. 217) instances a case of hail falling at Paruruma in the Orinoco valley on a plain near sea-level. He states that hail in the tropics generally falls only at an elevation of 300 toises (about 600 meters).

The Shaler Memorial Expedition encountered in July, 1908, at an altitude of 900 meters on the campos of São Paulo between Bury and Faxina (p. 13), a hailstorm which covered the ground as thickly with hail as do many similar storms in New York and New England.

I cite these instances of hailstorms with their attendant circumstances because hail presents us now with a means of precipitating ice at low altitudes in regions near the equator where snow never falls. Hailfalls appear to increase toward the hot regions of the globe and to diminish in frequency of occurrence towards the polar tracts. Thus the probability of glaciers originating from hailfalls in subtropical regions would seem to be as great as from snowfalls, provided the hailstorms came frequently enough to overcome the effect of melting due to the higher temperature of those parts of the earth's surface. Hailstorms like thunderstorms are secondary movements of atmospheric vapor normally engendered in the wake of cyclones of far greater size and with a much longer path, and we do not at present know what geographic conditions, if any, would cause in Permian times a succession of hailstorms sweeping with the regularity of

cyclones of the existing atmospheric circulation over the glacial fields. The distribution of land and sea in the Southern Hemisphere was then so different from what it now is, particularly in the Atlantic and Indian regions, that, while we may freely speculate upon a different system of distribution of aqueous vapor, it is at present impossible to construct an unassailable theory.

The "pendulationstheorie" of H. Simroth (1907) which is but a modification of the idea of a shifted axis of rotation does not better than the original conception explain the phenomena of distribution of Permian glaciation for the reason that no shifting of polar climates will bring the glacial deposits in the polar regions. Dr. Wilh. R. Eckardt (1910, p. 125–127) has well observed in connection with the above mechanical hypothesis that Sumatra, assumed to be one of the fixed equatorial poles of pendulation in this speculation, is placed on the borders of the principal area of Permian glaciation and hence no essential shift is accomplished.

The recently elaborated hypothesis that glaciation may be brought about through the temporary reduction of the amount of carbon in the earth's atmosphere appears to fail as an adequate explanation of the phenomena of glacial periods since the view does not explain the succession of epochs of glaciation and deglaciation in the Pleistocene period. Four times in this period the ice-sheets apparently came on and went off. If the abstraction of carbon in the form of coal and limestones in the preglacial period led to the first ice accumulation and advance, the hypothesis leaves unexplained the shortly succeeding ice advances between whose dates no corresponding appreciable reduction in the carbon is registered by rock-making in the earth's crust.

As we do not know with any certainty the cause of the latest glacial periods so near our own times, it is evident that the geographical conditions of the Permian must be thoroughly ascertained before we can construct a plausible explanation of a glacial period so remote and taking place on lands whose contours are as yet drawn with too much conjecture. Certain lights appear however to be burning as guides to the path which shall lead to the discovery of the probable cause of Permian glaciation. These may be briefly summarized as follows:—

The axis of the earth appears to have lain in Permian times where it does now. This excludes a favorite group of hypotheses.

The glaciated lands of south Brazil and German southwest Africa were in Permian time at or near sea-level. This does not exclude the extrusion of glaciers from highlands to the sea-border provided the highlands lay over the site of the Atlantic basin.

In the Northern Hemisphere on the existing shores of the Atlantic Ocean glaciated stones are found entering into the contemporaneous marine deposits much farther equatorward than those produced by the action of coast-ice and the same extension is true for the occurrence of glaciated ledges. Thus on the Atlantic coast of North America glaciated ledges and deposits of true glacial till line the shore of the United States as far south as New York Narrows in latitude 40° 30′ north; no modern observer has described stones or ledges bearing distinct traces of coast-ice action within this belt south of the British possessions, though it is to be acknowledged that thin sheets of coast-ice form in winter and may do some geological work of this character. The reason for this greater equatorward extent of glacier-ice as contrasted with ordinary sea-ice is due to the extent to which glacier-ice may be pushed equatorward beyond the gathering ground of the glaciers. In a like manner, glaciers originating on high lands in low latitudes may reach the sea-level and impress that region with marks of glaciation where the normal sea-level temperatures at the time preclude the existence of coast-ice. It can not be too much insisted upon, therefore, that glaciation is of all forms of ice-action that most likely to be met with in any marked degree at sea-level in low latitudes. Hence it is the more reasonable to assume that the Permian ice-deposits represent the existence of glaciers in the regions where these coarse accumulations occur, invoking as we may where the geologic evidence is permissible a favorable geographical relief such as now controls the distribution of glacial ice at one place or another on the earth's surface.

The rôle which hail might play in producing glaciers in subtropical regions as a complement to snowfall in higher latitudes and high altitudes is tentatively suggested as a factor in Permian glaciation, but the feasibility of the thesis encounters some of the same objections which meet the accepted origin of glaciers in snowfall.

There are accumulating evidences of the existence of glaciation in the Northern Hemisphere in Permian time, and there are not wanting signs of ice-action, probably floating ice, in the preceding Carboniferous epoch, facts which assist in the attempt to devise hypotheses.

The tendency of the geologic evidence is towards the recognition of glacial conditions independent of latitude which points to a weakness of the climatic zones, a feature characteristic of Palaeozoic temperatures, in which non-glacial climates show no zones corresponding to the present ones.

The hypothesis of internal heat controlling surface temperature

which has been advocated by Mr. Marsden Marson finds little support in the geological evidence derived from the occurrence of rocks at a high temperature over large areas beneath the surface. The great Triassic trap outflows of Brazil were erupted but shortly after the Permian glaciation in that field. During the epoch of glaciation the magma was still confined within the crust but had no recognizable effect in controlling surface temperatures or in preventing glaciation of the Permian land surface.

VI. THE TRIASSIC TRAP PLATEAU.

Overlying the Palaeozoic strata of the southern Brazilian highlands and either intruded in or interstratified with a group of red beds of presumed Triassic age is a series of trap sheets, mainly lava-flows, of vast extent, comparable in age and geological position with the basic igneous rocks of the so-called Newark group of the eastern coast of North America, and rivalling in their present surficial extension the Cretaceous lava-fields of the Deccan of peninsular India if not also the more recent lava-flows of the Columbia and Snake River basins of western North America. From the northwestern part of the state of São Paulo and the borders of Minas Geraes where the trap rests upon the Pre-Devonian schists, these sheets of trap form high plateaus broken through by the tributaries of the Rio Paraná as far south as central Rio Grande do Sul. From the sea-border near Porto Alegro in the latter state the trap formation extends westward according to the report of Dr. M. A. Lisboa as far as the Serra do Maracajú in Matto Grosso at a point 460 kilometers east of the Rio Paraguay or nearly 12 degrees of longitude west from Rio de Janeiro. The trap formation has been recognized over a breadth of country five degrees in longitude and some eight degrees in latitude between the parallels of 20 and 28 degrees south. The area in which these rocks dominate the surface is in round numbers about 100,000 square miles or approximately a region as great as that of the state of Nevada in North America.

In describing the geological features of the trap plateau in the Rio Pelotas basin, I shall use for the igneous rocks the non-committal term *trap* since it avoids the inexactness which might arise from the general application of such terms as basalt, augite-porphyry, etc., to which kinds of rocks certain parts of the trappean series have at one time or another been referred.

As is stated more explicitly in what follows I include in the area of

the Pelotas plateau a large tract about Lages in Santa Catharina in the headwaters of the Rio Pelotas from which the trap has been denuded so as to leave the Triassic red beds exposed at the surface. This region is separated from the trappean plateau of Paraná by the Rio Iguassú as far west as Porto da União da Victoria, some leagues west of which point the dissected trap plateaus of the southern Brazilian coastal states merge in the longitude of the Rio Paraná into a broad sheet with little topographic differentiation. Throughout Santa Catharina and Rio Grande do Sul the border of the trap area gives rise to high escarpments capped by trap sheets overlooking the Permian sedimentary tract. This escarpment with its varying relief and declivity receives local names. South of Rio Negro it is known as the Serra do Espigão which attains an elevation exceeding 4,000 feet. The main, almost unbroken, escarpment farther south and east is known as the Serra Geral.

The Trap Escarpment.— This line of escarpments has been interpreted as a fault cliff and as a true retreatal escarpment due to differential erosion. Doubtless small faults intersect the trappean series as elsewhere in the region but the descriptions of others and my own observations upon the escarpment in the Serra do Espigão and at the head of the Rio Tuberão leave no question in my mind that the escarpment is the effect of differential erosion on the Permian and Triassic beds capped by resistant sheets of trap.

At the head of the Rio Tuberão the Serra Geral is a typical steep-walled trap escarpment below the base of which erosion spurs and ravines of the sedimentary beds comprising the Trias and Permian are developed in sharp relief under the active headwater attack of the Rio Tuberão and its tributaries.

Inland in the region of the Serra do Espigão the alignment of the escarpment is less simple in its curvature. Siemiradzki in a section reproduced by Suess in "La face de la terre" assumes a normal fault along this line as he does also in the case of the "cuesta" of the Devonian sandstones but without structural evidence, and here also the topographic development of the rocks is simply a matter of secular denudation as shown in the geological section drawn by Derby and published by Branner in his Geologia elementar.

Siemiradzki represents the Serra do Espigão as a ridge of lava piled up above a dike. The northwestern spur of the Espigão forms a high terraciform ridge standing out above the trap plateau south of the escarpment but the table-like masses of which the ridge is composed indicate that it is a portion of the trap sheets left standing out in

consequence of erosion. In the section which can be constructed from the exposures along the road from Rio Negro to Lages at the pass through Collectoria it is possible that a fault can be traced cutting off the Espigão from the main mass of trap on the south at the right of the section in Fig. 24. But this interpretation of the

Fig. 24.— Section across the Serra do Espigão at the Collectoria on the road from Rio Negro to Lages.

tilted beds at the bottom of the valley and the apparently lower level at which the trap lies south of the stream crossing demands a throw of the normal fault on the south side in a manner nowise supporting the hypothesis that the escarpment is due to a fault. This northerly steep dip has by some been regarded as cross-bedding and is stated to occur elsewhere along the trap escarpment in the underlying sandstones.

Number of the trap sheets.— It is stated that there are four trap sheets or sets of sheets in the trap mass of the Serra Esperança on the

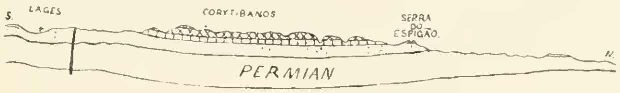

Fig. 25.— Cross-section of the Trap plateau from the Rio Negro to Lages. 1 (dotted). São Bento beds. Triassic. 2 (right lined). The Collectoria trap sheet. 3 (cross lined). The Corisco trap sheet. 4. The Third (and Fourth?) trap sheets.

north of the valley of the Rio Iguassú. In Dr. Derby's section the trap is diagrammatically represented as if composed of surface flows. The number of flows or sheets entering into the plateau between the Serra do Espigão and the sandstone area about Lages was not definitely determined by observation upon the ground but the plotting of the profile of the route and the outcrops of sandstones encountered in the trappean tract leads to the conviction that along this route there are at least three great sheets of trap separated by sandstone beds. The subjoined figure section (Fig. 25) gives the approximate profile and geological section along a line paralleling the road from

Rio Negro to Lages. The elevations are from aneroid readings and are subject to such a correction that the altitude as given may be 100 feet out. The structure as drawn involves a gentle folding of the trap sheets in accordance with the varying dip of the strata between the southern edge of the trap and Lages. The inclined bedding seen in certain sections exposed in stream bottoms is interpreted as due to displacement indicating downthrow along faults or else sharp flexures. An interpretation of the structure regarded by the writer as less probable than that above given demands the presence of four trap sheets and requires the existence of a fault of several hundred feet downthrow along the southwestern border of the trap in the upper waters of the Rio Canoas.

In either construction the trap in the pass over the Serra do Espigão at the old Collectoria appears as the lowest in the series. The north-

Fig. 26.— Trap ridges of northwestern arm of Serro do Espigão, seen from heights near Corisco.

western branch of this trappean ridge as seen from the heights near Corisco shows three distinct tabular masses rising above a common level which may be that of an underlying trap sheet. A four-fold division of the trap series is there strongly suggested. The fact that one of the great trap sheets may consist of more than one flow without intervening beds of sandstone or shale makes it impossible to rely implicitly upon topographic profiles. The locality laid too far from our route to be geologically examined.

The lowest bed of trap on this route which I have called the Collectoria sheet is relatively thin, according to a rough estimate given below and based on a mule-back transit, about 300 feet. It appears to form the surface along the line of the Lages-Rio Negro Road as far south as the crossing of the Rio Correntes, where the second sheet or Corisco flow is encountered. Along our line of route the upper surface of the first flow or sill was not seen and though I am inclined to regard it as an effusive sheet I am not able to point out local evidence for such a conclusion.

The Corisco sheet is, according to my rough measurement, the thickest of all and has the greatest surface exposure in this district. This sheet forms the surface of the plateau along the road from Corisco to Coritybanos. The trap is moderately dissected by numerous streams. Amygdalar trap abounds on the higher parts of the surface

affording presumptive evidence that the sheet is an effusive flow. The road from Coritybanos northwestward to São João traverses the deeply eroded surface of this sheet across the campos of Guarda Mor. In fact the upper waters of the Rio Marombas and its tributaries, the Rio das Pedras and the Correntes, mainly lie on this surface.

South of Coritybanos there appears to be good reason for considering the high trap mass there encountered as an outlier of a third sheet limited on the south by the Rio das Cachoeiras. This mass seems on account of the sandstones which crop out on its southern slope to be divisible into two beds of basalt. If this interpretation is correct, the top of the hill is a remnant of a fourth trap sheet in this area.

Thickness of the Trap Sheets.— Exact estimates of the thickness of the several trap sheets are not possible from the notes I have; but the following approximations are thought worth recording as giving the order of magnitude of the thickness of the sheets. The estimate postulates the supposition that the base of the Corisco sheet is to be seen on the south bank of the Rio Correntes at an altitude of ca. 3,400 feet, and that its upper surface passes beneath higher beds in the vicinity of Coritybanos at an elevation of ca. 3,200 feet. By graphic construction the sheet is found to be ca. 600 feet thick (190 M.). The overlying trap remnant south of Coritybanos consisting possibly of two flows must be nearly 600 feet (190 M.) thick with the intercalated sedimentaries. The basal bed or Collectoria sheet on this estimate would be about 300 feet (95 M.) thick. The total thickness of the trap sheets would thus be about 1,500 feet (475 M.).

Origin of the Trap Sheets.— No known volcanic necks or explosive vents have been reported in connection with these sheets. In the region which I visited the succession of sheets is suggestive of surface flows and the Corisco sheet is very probably of that nature. Far to the southeast in Rio Grande do Sul, Dr. I. C. White has described the occurrence of sills and intrusive masses of trap as if breaking up through the sediments into the horizons occupied by the sheets in a manner to support the theory of fissure eruptions for the origin of the true flows of this region. In our journey across the sandstone tract north of Lages one noteworthy dike was encountered presenting characters which bear upon the mode of origin of the trap sheets. That occurrence will now be described.

The Dike with Inclusions North of Lages.— About 8 kilometers north of Lages on the road to Coritybanos there is to be seen a remarkable dike agreeing in petrographic character with the neighboring trap sheets on the north and probably to be regarded as a feeder to one of

them. This dike crosses the road in a direction N. 70° E. (magnetic) having a width at the road of 23 meters (75 feet). The sandstones on the north side of the dike strike north-south (magnetic) and dip ca. 5° west. The sandstone on the south side of the dike strikes N. 23° W. (magnetic) and dips 7° west. West of the road the dike is traceable by means of small weather-boulders in a brook for about 1,098 meters (3,600 ft.) but the trace of the dike to the east of the road was not followed. (See Plate 18.)

In the disintegrated rock of the dike there are crystals as large as a hen's egg of a now rusty black augite and large flakes of a black mica carrying holes from which some included mineral of earlier genesis has been dissolved out. A soft, white, partly altered, mica is probably bleached biotite. The feldspar constituent was not observed.

The most striking feature of this dike is the large number of inclusions of foreign rocks which it contains. These constitute at the exposure in the road quite one half of the volume of the dike and comprise at least the following varieties of older rocks, viz: —

Red sandy shale in fragments up to 51 cm. (20 inches) diameter.

Red shale; also a black shale.

Coarse grained basalt with lathe-shaped feldspars.

Fine grained basic rock.

Amygdaloidal basalt.

Greyish amygdaloidal basalt, less vesicular lava than the preceding.

A fine-grained, dark, thin-laminated rock weathering white, origin not determined.

The fragments of sedimentary rock may well be regarded as disrupted from the walls of the fissure which appears to have been the locus of a vertical displacement of the strata. Presumably the fragments came from underlying strata though they may just as well have fallen in from above. The vesicular lavas of different types, unless there are flows buried beneath the Lages area of sandstones, contrary to my own determinations of the geological structure and those of Dr. I. C. White, must have been derived from overlying lavas. Though rarely, amygdales form vertical bands in dikes, they are characteristic of lava-flows or of lava which has been raised to the vent of a volcanic conduit. This dike apparently communicated in its time with the surface and permitted lavas already extravasated and cooled to yield fragments which sank in the still fluid magma of the dike. So much of the history which appears in the nature of the phenomena leads to the further conclusion that the dike communicated at the time of the infalling fragments with the Corisco, or some yet

higher sheet. From these observations it is to be inferred that fracturing of the underlying sandstones and the migration of the basic magmas towards the surface went on during the period of great trappean outbreaks presumably with a foundering of a vast area which became flooded with successive sheets of lava from many fissures. Between one and two kilometers south of the dike above described another but much narrower basic dike about a foot wide crosses the mule path near a small stream. An extended search would probably reveal many other dikes once serving as feeders to the overlying trap sheets.

The Lages Area.— For several leagues around Lages the trap sheets have been denuded leaving the Triassic sandstones and shales of the São Bento beds of Dr. I. C. White's report at the surface apparently in an anticlinal dome. On the northern margin of this tract the trap overlooks it with a well-defined, but much notched, escarpment rising a few hundred feet above the general level. At the eastern limit of vision from the Lages road, a conical outlier of the trap forms a prominent hill, showing that along this line, as on the face of the escarpment overlooking the Permian territory, erosion and not faulting has produced the trap escarpment.

The Lake Basins of Santa Catharina.— "La province de Santa Catharina est couverte de petits lacs." (Malte-Brun. Geographie 1857, **6**, p. 687.) In the interstream areas of the trap surface large tracts frequently depart widely in their slopes from the sculptured forms produced by running water. The surface becomes undulating with saucer-shaped pits always opening out on one side towards the drainage way of the district. As the small basins become deeper and more numerous, inosculating rounded ridges rise between them, giving such tracts the appearance of New England kame-kettles and their winding kame-ridges. In the pits there are shallow lakes or pools. These depressions and ridges are evidently the work of long continued secular weathering of the basalt combined with the removal of the products of disintegration and decomposition.

Most of these basins were at the time of my visit more or less occupied by standing water, some of them forming shallow lakelets in which grew a brilliant green grass. Other basins presented the appearance of level meadows from the filling of presumably residual clay and vegetable matter which they contained. At São João on the trap plateau south of Porto da União, a pit some three or four feet in depth had been dug in one of these floored depressions, showing beneath a few inches of vegetable matter a light colored clay evidently the product of decomposition of the trap rock.

The exposures of trap on the rounded ridges which separate the basins are usually crusted with superficially segregated oxides of iron, and loose weathered blocks are not infrequently seen in positions to indicate the almost complete absence, for a long geological period in the past, of any transporting agency such as sliding snow, ice, or running water.

A B

Fig. 27.— Basins of decomposition on the Triassic trap plateau. A, cross-section of basin overhanging a stream valley. B, contour map of lakelet converted into a swamp. Santa Catharina.

There is thus no reason for supposing that the basins are due to other causes than deep secular decay and the slow wasting away of the rock under a moderate rainfall. That these weathered basins are of great antiquity is obvious from the consideration of the mode of origin which thus may be ascribed to them. There is no clear local indication of the geological date of beginning of the basins. Inasmuch as they abound on the surface of the Corisco lava-flow above described they, in this instance, are more recent than the erosion of the overlying sheets of trap. I saw nothing in them by which to distinguish Pleistocene from Tertiary processes unless it be the deposits of clay which would argue for probably a Tertiary date as the time of beginning of the corrosion, but they may be early rather than late Tertiary.

Such solution-basins are not limited to the trap plateau but are to be seen here and there on the Permian area in São Paulo where springs find their way to the surface.

Mr. T. A. Allen (Derby, 1906, p. 388) has described pot-holes often of great size and containing water, in the gneisses to the east of the Serra do Esperanço on the plains of Bahia. He regarded these pits as due to a peculiarly localized action of disintegration.

Professor Pumpelly (1879, p. 136) has called attention to the manner in which deep secular weathering followed by a period of active erosion as by ice would result in the production of a topography quite unlike that of normal land sculpture by streams. He notes that "as masses

of decomposed rock may be observed to a depth of over 100 feet, the surface of the still solid rock underneath presents ridges and hollows, succeeding each other according to varying durability under the influence of percolating carbonated water. In this kind of weathering, where erosion does not come into play, it is evident that the resulting topography must, in some important respects, differ from that of an ordinary surface of superficial denudation. In particular, rock basins may be gradually eaten out of the solid rock. These will remain full of the decomposed material, but any subsequent action, such as that of glacier ice, which could scoop out the detritus, would leave the basins and their intervening ridges exposed."

VII. GEOMORPHOLOGY OF SOUTH BRAZIL.

In the preceding chapters so much has been stated concerning the form and relief of the tableland of south Brazil, in describing the structure and position of the Permian glacial beds, that little remains in treating specifically a sketch of the geomorphology of the region than to summarize the matter in more systematic terms with the added enumeration of certain details.

Regarded as a land form south Brazil is an elevated tableland with a short steep slope descending to and below the Atlantic sea-level and a long gentle slope towards the interior of the continent. The surface of this warped mass appears to have been in Cretaceous times much more nearly a plane. Since its elevation and warping it has been dissected by streams which have etched out the structure of the westward dipping beds of the long westward slope into lines of escarpments formed of the edges of the harder more resistent beds overlooking lowlands.

For convenience of treatment the region may be divided into two districts which by their geological nature and relief at once impress the visitor to Brazil. First, the steep coastal border of the Serra do Mar, and second, the tableland or planalto proper.

The Serra do Mar, notched and pinnacled in the states of Rio de Janeiro and São Paulo, declines to the southward, and in Santa Catharina retains more of the character of the warped surface of mature relief which appears to have been characteristic of the whole belt in an early stage of its development following the warping above noted. In eastern Paraná the summits of the Serra do Mar form a line of peaks and ridges rising well above the eastern portion of the tableland

FIG. 28.— Crests of the Serra do Mar seen from the west on the tableland near Curityba, Paraná.

or of the locally baselevelled tracts developed between the more resistent members of the tableland. The annexed diagram of the mountain crests as seen rising above the lowland east of Curityba is typical of the region for many leagues northward into the state of São Paulo.

Isolated summits in this region rise somewhat above the level of the trap plateau. It is probable that in the late Mesozoic baselevelling of the region the granitic bosses and some of the gneissic areas were not reduced to the general level. On the north the lofty Serra da Mantiqueira culminating in Mt. Itatiaia nearly 10,000 feet in elevation, warrants this statement.

The slope from the crest of the Serra do Mar to the sea is generally steep. It is deeply ravined by short streams. The interstream areas form sharp spurs which in some portions of the slope are deeply dissected, standing out as isolated peaks and mountain blocks as on the south side of the harbor of Rio de Janeiro. The immediate descent to the sea is often so precipitous and the relief so high that where the geological structure is permissive of the hypothesis down-faulting on the ocean side has been advocated as by Dr. Derby as a factor in the production of the topography.

This deeply dissected slope has been depressed beneath sea-level since its dissection arrived at an advanced stage. The submerged valleys form harbors and reentrants such as those of Rio de Janeiro,Santos, Itajahy, São Francisco, and Florianopolis.[1] Since this depression in relation to sea-level took place, a slight uplift of about ten feet (3 meters) has occurred, raising up in the form of a platform about bay shores a recent deposit of littoral sands,

[1] The frequent repetition of the circumlocutions one is obliged to employ in expressing concisely the fact of our ignorance as to whether the land has sunk or the sea-surface risen when reference is made to a change of level of land and sea becomes intolerable in writing at length of such matters. Suess's terminology partially avoids the embarrassment but does not provide a name for a change of level of land and sea. The French term *denivellement*, a variation of level, suggests the use in English of its natural equivalent *delevelling* in analogy with *baselevelling*. A positive delevelling thus becomes a depression of the land in relation to the sea-level, and a negative delevelling an apparent elevation of the land in relation to the surface of the sea.

which also surround former rocky islets and unite them to the mainland.

Off the coast from the entrance of Rio Harbor southwestward to and beyond Laguna, low rocky islets of granite or gneiss reveal the continuation of the dissected slope of the Serra beneath the sea. These islands are of small size and mostly uninhabited except by occasional fishermen or as they may be the site of a lighthouse. Navigation between them is dangerous because of the fogs at certain seasons of the year and for the reason that lesser islets, or rocks which just reach the surface of the sea, are not wanting.

These off-shore islands are frequently partly surrounded by a platform of rock rising a few feet above sea-level. These benches correspond to the elevated strips about the bays and probably indicate the extent to which the subaerial upper portion of the island was reduced by weathering and the attack of the sea above the level of these platforms during the episode of maximum depression.

Bordering the inner shore of the bay of Paranagua, there are remnants of siliceous sands of presumably Tertiary date which appear to have been deposited within the dissected slope of the Serra do Mar, showing that the basal portion of the coastal slope was well dissected before the close of the Tertiary periods.

Professor Hartt found evidence at various points along the coast that an elevation or negative delevelling had recently taken place. Whether the coast from Rio de Janeiro southward is now undergoing a slow delevelling or not I could not ascertain. Faint traces of an old beach not now reached at high tide near Paranagua favors the idea of a recent elevation there.

The hypothesis above advanced of the warping up of the south Brazilian plateau with the axis of curvature along the Serra do Mar belt and the reference of the now dissected surface of a former peneplain to a Cretaceous date is based upon the fact that in the region of Bahia the Cretaceous strata extend far inland. It is thought that similar conditions prevailed on the south during a stage in the evolution of the present topography, that with the negative delevelling and the development of a steep slope to the sea and a gentle slope towards the interior the Cretaceous strata were denuded in early Tertiary time. The Tertiary basin in the valley of the Parahyba between the Serra do Mar and the Serra da Mantiqueira is taken as evidence of uplift and dissection of the Cretaceous peneplain prior to the deposition of the Tertiary fresh-water beds. The definite determination of the date of the Tertiary deposits would fix the limits of time to be

placed upon the epoch of dissection. (Branner, 1906, p. 283. A. S. Woodward, 1898, p. 63–75). Some warping of the surface has apparently taken place since the Tertiary beds were deposited.

At the northern limits of the region under discussion the Serra da Mantiqueira rises as a long lofty monadnock range in the Pre-Devonian terrane. The western slope of the crest of this gneissic mass subtends the surface of contact of the Permian of São Paulo upon the same ancient rocks. It therefore appears probable that in the Serra da Mantiqueira we have a remnant of the Permian floor east of the present line of outcrop of those strata.

Between the Serra do Mar and the escarpment formed by the westward dipping Devonian sandstone cuesta [1] there is a high level tract belonging to the planalto or tableland. On the South in the headwater region of the Iguassú about Curytiba it is essentially a peneplain and swamps of great extent exist locally. But in southeastern São Paulo an Atlantic stream, the Rio Ribeira de Iguape, has breached the Serra do Mar and gnawed a deep ravine with its headwaters pushed against the crystalline Serra da Paranapiacaba for a watershed. The situation of this stream, the single example of any size to push its headwaters past the Serra do Mar and drain the planalto, in the great concave arc formed by the Paranapiacaba and the Devonian sandstone cuesta is evidently an effect of the Devonian sandstone ridge. The almost level crest of this Serra indicates the approximate level of the Cretaceous peneplain up to which level the plateau was filled with rocks before the present valleys and widened out lowlands of the planalto were excavated. Under these conditions the Devonian sandstones must have extended much to the eastward, possibly to the Serra do Mar crest. In the dissection of the country east of the present retreatal escarpment of the Devonian sandstones the Rio Ribeira de Iguape, protected from capture by the westward flowing streams, has worked backward following the shifting of the watershed formed by the retreating cuesta until its headwaters are in a position almost to capture the Rio Yapo and the uppermost Iguassú. (See map, Fig. 7, p. 43.) The short course and steep gradient of the river have enabled it to cut its present profound ravine. A similar history probably is true of the Rio Tuberão which in southeastern Santa Catharina has excavated its valley across the granitic terrane,

[1] The term cuesta used in a technical sense in North American writings on geomorphology for obvious reasons is not adoptable in Portuguese. "Costa do outeiro" misses the point in the English use of the Spanish name cuesta. Serra monoclina expresses in structural terms the essential characteristic of a cuesta.

corresponding there geologically to the Serra do Mar, and which has its watershed in the lofty crest of the Triassic escarpment on the west of the Permian belt of coal-bearing shales.[1] The Ypiranga, an affluent of the Bay of Paranagua, is apparently in the act of tapping the westward sloping surface of the planalto back of the Serra do Mar.

According to Drs. Derby and Euzebio P. de Oliveira the Permian sandstone overlaps the Devonian shales at places in Paraná and rises towards the crest of the Serra as at Vilha Vehla, a point of deeply disintegrated rocks southeast of Ponta Grossa, the name Vilha Vehla being applied in the same sense that "Rock City" is employed in North America. This ridge dies out northward in São Paulo and southwards in Paraná so that in Santa Catharina the geologically higher escarpment of the trap plateau on the south comes in as the first range inside the coastal mountain belt.

The relatively even sky-line of the Devonian cuesta forms a striking feature in the treeless landscapes for many miles in Paraná. The summit attains elevations exceeding 3,000 feet and approaches the level of the hypothetical Cretaceous peneplain out of the nearly level surface of which the lowlands between the ridges and plateaus of the planalto have been sculptured by Tertiary and more recent erosion. In northern Paraná and southern São Paulo the topographic relief becomes complicated by the erosion of longitudinal valleys and by the association of ridges developed on the lower Permian sandstones which succeed on the west of the Devonian outcrop. The streams in this district also have cut deep gorges across these ridges apparently along lines of drainage inherited from the time when they flowed on the Cretaceous peneplain. Such appears to be the origin of the defile in the massive sandstones through which the Yapo flows in the country northwest from Castro to Tibagy. At Joachim Murinho Station the railway follows a broad gap in the sandstones which appears to have been once occupied by a river much larger than the present stream. The escarpment of the Devonian here becomes very irregular by reason of dissection. The steep sandstone cliffs form precipices overlooking lowlands excavated to the level of the crystalline rock-floor as at Pirahy. A characteristic view is to be had from Fabio Rego Station looking towards the cliffs of the Serra Morumgaba surmounted by the Morro do Chapeo.

[1] For some account of the Ribeira de Iguape with maps and plans see a report entitled Exploracão do Rio Ribeira de Iguape. Comm. Geog. e Geol. de S. Paulo, 1908.

The Devonian shales in central eastern Paraná give rise to a longitudinal valley but the non-resistent character of these rocks is locally counteracted by intrusions of diabase. The western side of this longitudinal valley, where it is developed, is formed by sandstones and conglomerates of the basal Permian. Ponta Grossa stands on the western side of this valley.

The sandstone and conglomeratic members of the Permian form an irregular grouping of uplands separated by river valleys. The level at which the hilltops stand, intermediate between that of the lowlands and the trap plateau and the Devonian cuesta probably indicates an intermediate stand of the land, the date of which is difficult to determine. The valleys of such rivers as the Tieté in São Paulo certainly have been excavated since the Tertiary deposits which underlie the city of that name. It seems highly probable therefore that the uplands in the Permian tracts antedate not only these Tertiary deposits but also the erosion of the depressions in which the beds were accumulated. The date of the evanescent peneplain with which the summits of the upland areas accord must be placed therefore in early Tertiary time.

The westward flowing drainage of the planalto gives rise to the dissection of the Permian terrane by long westward aligned valleys such as those of the Paranapanema and the Rio Negro, but the tributaries of the latter river including such large streams as the Tibagy flow obliquely across the trend of the Permian belt on courses expressing the resolution of the double control of the westward dip of the formation on the one hand and of the slope towards the master stream developed by concentration of the drainage on the other. The Rio Negro displays a rectangular adjustment of its course to the strike and dip of the Permian strata.

In the latitude of Curityba there is traceable westward from the vicinity of that city a divide between the waters which drain northward into the Paranapanema and southward into the Rio Iguassú. This watershed includes the Serrinha, passes south of the towns of Palmeira and Iraty and thence joins on the west the trap escarpment known as the Serra da Esperança. The great extent of the drainage basin of the Rio Paranapanema as compared with that of the combined Iguassú and Rio Negro in the Permian terrane is apparently a consequence of the antilinal axis, which, normal to the arc of the outcrops in eastern Paraná and southern São Paulo, caused the Palaeozoic beds along this east-west line to stand relatively high and erode more rapidly. As a result of this distribution of the drainage

the headwaters of the Rio Paranapanema drain almost entirely the western slopes of the Devonian beds, as does the Ribeira de Iguape the crystalline terrane on the east of the Devonian sandstones.

The Permian tract is bounded on the west by the Triassic escarpment of sandstones crowned by trap sheets. The westward dip of the formation combined with the flow of the streams in that general direction has caused the trap to retreat far to the west along the axis of the main drainage lines, such as that of the Paranapanema and the Iguassú. In the western part of the south Brazilian states of São Paulo, Paraná, and Santa Catharina the rivers flow over the trap sheets whose resistance to erosion holds up to their local baselevel the entire drainage area of the planalto. The Rio Paraná on the confines of Brazil and Uruguay is gnawing back the southern edge of the trap sheets. Below the cascades and falls the river joins the drowned valleys of the La Plata system.

The rate at which the falls of the Paraná and Iguassú are receding has not I believe been determined. But it is evident that the rivers have cut back from the southern edge of the trap sheets since the land had something like its present elevation above the sea. If the land at the confluence of the Iguassú and the Paraná had been as long above sea-level as it has in the upper valley of the Iguassú, where the trap has been swept away over a large tract of the Permian, it is inconceivable that the youthful characteristic of falls and cascades should still persist. We are therefore compelled to conclude that the country immediately adjacent to the Paraná and Paraguay rivers has recently been uplifted in relation to the sea. As on the south of the trappean country in Banda Oriental there are marine Tertiary beds now above sea-level (Darwin, 1846, p. 1–3) and as along the coast of Brazil from north of Rio de Janeiro to the Amazon (Derby, 1907, p. 218–237) there are evidences of uplift since the Tertiary beds were there laid down, it seems a valid hypothesis that the excavation of the Paraná channel in the traps began in later Tertiary time through an uplift of the whole planalto of Brazil.

The upper courses of small streams in eastern São Paulo and northern Paraná generally flow in narrow gorges so recently cut that many side streams particularly of the wet-weather type enter by a fall over the brink of the gorge. Without a thorough understanding of the local baselevels of the Paraná system it seems out of the question to infer the cause of this revived stream-action.

A remarkable example of one of these streams is the Rio Itararé flowing north into the Paranapanema along the boundary between

the states of Paraná and São Paulo. Near the town of São Pedro de Itararé at the railway bridge this river flows in a channel which at one point in its cross-section is not more than three feet wide.

The channel lies in the white Devonian sandstones which present no great variation from layer to layer offering opportunity for the

Fig. 29.— Map of the Parahyba and Tietê rivers in São Paulo (After H. Williams).

selective solution which in limestone countries often produce similar gorges. The bottom of this gorge is said to be between 62 and 63 meters below the railroad bridge.

At one point west of the railway bridge there is a natural bridge of the sandstone which evidently points to the origin of this gorge as an underground stream.

It remains to note the curious course of the Parahyba in relation to the headwaters of the Rio Tieté in eastern São Paulo. The annexed map, traced from that of São Paulo by Mr. Horatio Williams, late of the São Paulo Geographical and Geological Commission, sets forth the pattern of the streams. (Fig. 29.)

It will be noted that the upper course of the Rio Parahyba under the name Parahytinga follows a southwest course to the great bend at Guarerema whence the course is northeastward to the sea beyond the limits of the map. These courses are in essential adjustment to the structure of the underlying Pre-Devonian rocks but the basin of the river below the great bend is largely formed by the Tertiary non-marine beds before mentioned. The great bend is made by a transverse gorge cut through the Pre-Devonian series which rise a few hundred feet above the riverplain. It is therefore to be presumed that the course of the river at this point is inherited from a former course which lay at the level of the intervening hill-tops. This earlier

stage of the river presumably was developed on the surface of the Tertiary beds.

The divide between the Tieté at Mogy das Cruzes and the great bend is occupied by rock-hills of low relief rising about 200 feet above the weakly developed drainage lines of the district. The natural course of the Parahytinga would appear to be westward into confluence with the Rio Tieté of which it may be regarded as a beheaded portion, captured by the Rio Parahyba, which, pushing its head southwestwards along the easily eroded Tertiary beds, diverted the stream before erosion had swept away the Tertiary beds between the Parahyba basin and that of the Tertiary beds at São Paulo.

The Pleistocene and Recent Formations.— The discrimination of the Post-Tertiary changes in extra-glacial regions into Pleistocene and Recent is attended with difficulties. In Brazil the surface deposits are prevailingly residual clays or clays, sands, and pebble beds derived from the secular washing and transportation of weathered Pre-Pleistocene formations. Great differences exist as to the depth of the decayed rock even on the same formation. Where the rainfall is heavy at certain seasons of the year, the slope of the ground steep, and the run-off effective, the decayed materials are removed nearly as fast as their disintegration or decomposition is accomplished and thus nearly fresh rock occurs at the surface. I was frequently surprised in the valleys of the Rio Negro and the Rio Tuberão by the apparent freshness of carbonaceous shales at a depth of a few centimeters below the surface but in these situations erosion has been and still is actively in progress.

The new cuts of the railway in construction from Bury in São Paulo via São Pedro de Itararé and Jaguariahyva to Ponta Grossa in Paraná gave at the time of my visit an unusual opportunity to see many excavations in the mantle rock. Along the banks of the Rio Jaguaricatu in the Permian tillite beds these cuttings were often from 5 to 10 meters deep. At these depths most of the pebbles were still undecomposed.

At numerous localities along the railway line across the mature topography of southern São Paulo and Paraná the rounded swells between streams display traces of ancient gravel beds usually with concave lower limits as if occupying old stream channels long since abandoned. The same phenomenon is observable in a pronounced manner where the railway from Ponta Grossa to Serrinha Station in Paraná skirts the lower westward slopes of the sandstones of the Devonian cuesta. In all these cases the history of the surface appears

to be as follows: — The streams and wet-weather wash concentrate pebbles in their beds leaving the interstream swells or rounded ridges comparatively free from coarse material. The finer decomposed material of the interstream areas becomes more readily eroded than the coarse débris in the stream channels and erosion proceeds more rapidly

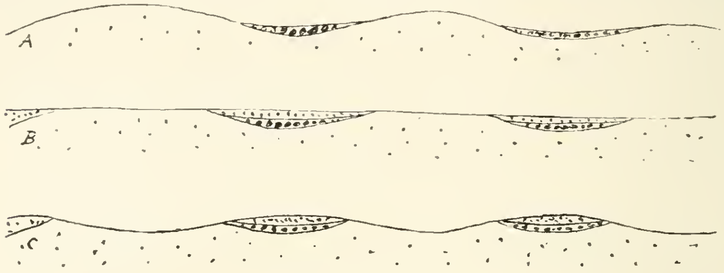

Fig. 30.— Showing supposed stages, A. B. C., in the concentration of gravels in creases and the deposits on ridges between creases on the dip-slope of pebbly sandstone beds.

along them so that they become depressions between the old deposits. Concentration of coarse débris begins again in the now new well-defined creases which carry off the rainfall. So far as my observations go there have been but two cycles of such gravel accumulation, an ancient one and that now actually taking place. If the process depends solely upon the relative resistance to erosion of the gravel-bearing creases and the gravel-free ridges between streams the change may well be automatic under a constant rainfall during the period of alteration. After one such shift the interstream areas become partly gravel-capped and an equilibrium is established which at first did not exist. Thus the dual character of the phenomenon in Brazil may be due to this limitation inherent in the nature of the process, even with a variable rainfall.

In the case of the deposits of this nature on the Serrinha near Tamanduá in Paraná the ancient gravels occur in abundance and appear to exceed in thickness those of the present wet-weathered channels. That these older gravels in this climate are as old as the Tertiary period seems to me improbable since under the conditions of exposure to weathering they must have broken down. At best they might be Pliocene, but if it is admitted that the glacial epochs of the Pleistocene were signalized in south Brazil by a heavier rainfall than that now prevailing it is probable that the older gravels represent one

of the older glacial episodes comparable to that of the Columbia gravels south of the terminal moraine on the Atlantic slope of North America.

A short distance west by south from Araucaria Station in Paraná near kilometer post 26 on the railroad from Serrinha to Curityba I

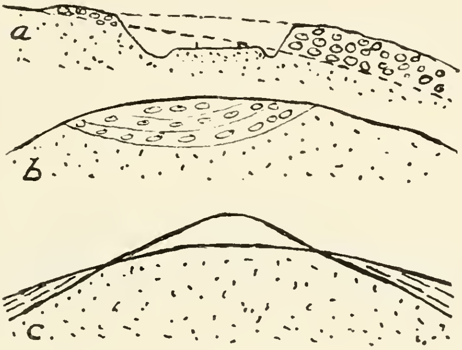

FIG. 31.— a, cross-section of the road cut in which the upper dotted line gives the present slope, the lower one, the slope on which the old gravels were deposited; b, cross-section of the spur on right of railway; c, theoretical restoration of both sides of a gravel-bearing hill, the upper portion being removed in the segregation of the gravels.

noted, in a railway cut through a spur, evidence that these old gravels were deposited on a steeper slope than that of the modern neighboring creases. The relations of the ancient and modern profiles are shown in the annexed diagrams. The gravel bed was evidently deposited in a crease, the axis of which corresponds with that of the present spur as above explained. From the consideration of such a case it becomes evident that the existing smoothened contour of the ground is due to the removal of the crests of old spurs and ridges and the accumulation of the coarse detritus near the bases of the slopes, and thus that a topography of sharper outlines preceded the present cycle. This means a considerable lowering of the elevations of the region since the old gravels were deposited and confirms the idea of an early Pleistocene date at least for the age of these deposits.

On the baselevelled plain about Curityba where rounded ridges of mature dissection modified by deep weathering are interspersed between shallow water courses the cuts show many signs of the gentle processes of solution by which the surficial rocks have been removed. In one such cut near the Meteorological Station in the west bank of

a small valley there was exposed in 1908 in the road the section diagrammatically shown in Fig. 32.

A quartz vein about 2 inches (5 cm.) thick dipping E. 30° in a section of decomposed schists had given rise to a sheet of quartz fragments at the base of the residual structureless surface deposits

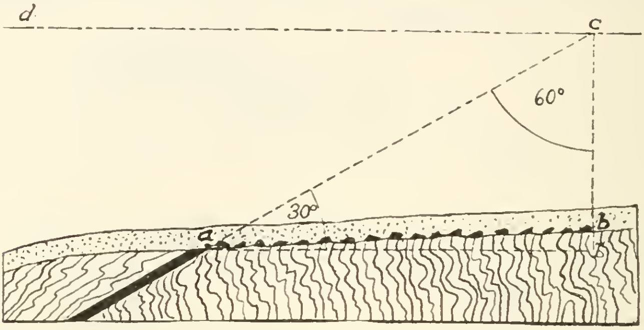

Fig. 32.— Train of residual quartz fragments derived from a vein during the weathering and ablation of the crystalline schists. Near Curityba, Paraná. a–b, a distance of 50 feet from the outcrop of the quartz vein to the limit of fragments; c–d, the supposed surface at which the vein outcropped.

traceable fully 50 feet (15.2 M.) to the westward on the gently inclined surface of the schists. The original aerial extension of the quartz vein from the data here presented must have been at a height of 29.5 feet (8.1 M.) above the present surface as may be readily determined by a calculation of the right angle triangle. The two to three feet of overlying structureless residual clay may or may not represent the breaking down of about thirty feet (9.15 M.) of rock above the present surface of the schists. In either case solution by percolating water has been the chief agency in denudation. If the removal of this thickness of rock went on at the average rate for such drainage areas as have been studied — a rate as great as one foot in 3,000 years, the time represented in this case for the lowering of the quartz fragments is approximately 88,500 years, a period which takes us back according to the newer[1] estimates to the close of the last glacial epoch in North America. To this estimate should be added the time for the accumulation of the overlying clays whose superposition on the quartz

[1] The most recent studies of the retreat of the Wisconsin ice-sheet and the glacial lakes and marine phenomena which succeeded the glacial retreat demand from 5 to 10 times the 10,000 years of earlier estimates.

fragments seems to point to some shifting of the residual clays. The definite termination of the band of quartz fragments at a distance of a few yards from the outcrop of the vein means that this old surface was at the beginning of the period of weathering swept clean of quartz fragments, either because of a steeper slope than that now found at the locality or by reason of a more powerful run off. This latter possibility is consonant with the hypothesis of a heavier rainfall during the Pleistocene, however much the above attempt to calculate the time employed may vary from the true duration of Post-Tertiary epoch.

River Terraces.— Along several of the larger rivers of south Brazil there are terraces of sand and gravel evidently remnants of a former aggraded floor of their valleys. These deposits date back presumably to the Pleistocene with its greater rainfall.

For examples, a terrace occurs in the Rio Iguassú between kilometer posts 47 and 48 along the railway between Araucaria and Balsa nova Stations in Paraná; a terrace also occurs north of Balsa nova at km. post 59. Other fragments of this terrace occur along the river further up the valley.

The Rio Capivary in Paraná between Lago and Palmeira exhibits a terraced plain.

In southern São Paulo a gravel terrace of old river cherts is crossed by the railway between Herval Station and Engenheiro Hermilho Station.

These gravelly terraces, apparently of the same epoch as the Tamanduá gravels on the hillsides, are probably in their later stages derived from the washing down and gullying of these deposits. Owing to the nature of river changes it is improbable that the formation of the terraces by reexcavation of the old valley floors should have been synchronous throughout the area under discussion.

Numerous cuttings along the railways in São Paulo and Paraná show that the clayey deposits there, varying but little from the *terra roxa* and the *terra vermehlo,* are not strictly residual but are rather transported or shifted, however much they have decayed in their present sites. Dr. Derby expressed the opinion that the red earth, of which an excellent exposure was examined at the railway station in São Pedro de Itararé on the confines of São Paulo and Paraná, was an equivalent of the loess of other regions.

The thickness of these deposits varies greatly. Many sections were seen varying from six to ten feet, but in many the bottom was not exposed. The material appears to be developed particularly

along the lower slopes of the hills as if washed down by rains during the wet season. Much dust is blown about by the winds in the dry season and doubtless an eolian origin may be attributed to some of the particles.

The relations of the red earths to the underlying pebble beds indicate pretty clearly the order of magnitude of the powers of the rainfall in the immediate past and the changing climatic conditions, a heavy rainfall with a strong run-off followed by a marked weakening in this agency. Wind action if registered in the loess-like red earth hardly can be called upon in the case of the gravels in old creases. Lag-gravels are typically developed upon wind-swept plains; besides glyptoliths or sand-carved pebbles are not here forth-coming; farther north in Brazil Dr. Lisboa has found them.

These deposits are related to each other in the range of dynamic force concerned as are the Pleistocene glacial gravels to the Post-glacial alluvial deposits of many North American sections. Hence the probability that the gravels represent the Pleistocene. From an excellent exposure in Paraná at Tamanduá Station I propose the name Tamanduá (anteater) beds for the gravels. As for the overlying shifted reddish earths whether *terra roxa* or not, they form a group of surficial deposits blending in places with residual clays *in situ* and do not so readily take a formation name.

In railway cuts in the white sandstones between São Pedro de Itararé and Fabio Rego the red earth rests on the eroded surface of the white sandstones. The sharpness of the contact between the two and the absence of red coloring in the sandstones proves the shifting of the superficial deposit with its coloring matter. The development of the red oxide of iron would seem here to have antedated the transportation of the material otherwise the red matter seemingly should have been carried downward into the porous sandstones.

In the winter season of drought the red earth dries and cracks. These cracks on the surface of newly cut banks by the railway stations often form a hexagonal network. Similar cracks form over the surface of the campo. As leaves, sticks, and insects peculiar to the existing flora and fauna readily fall into these cracks to some depth in the clays, it is obvious that by the closing and opening of these cracks under the changing seasons any contemporaneous fossils they may be found to contain must be carefully discriminated from post-depositional entries.

Canga is a superficial segregation of oxide of iron or limonite in various geological positions. On the road from Ponta Grossa to Conchas in

Paraná it forms crusts in the surficial decomposed portion of the bed rock. In a railway cut on the banks of the Iguassú near Serrinha Station in Paraná the outer portion of the Carboniferous rocks is crusted with canga and this vein-like material there occurred in joints. The segregation of canga by percolating water seems mainly to be ancient; it may be older Pleistocene or still older, and probably is not peculiar to any one episode of the modern geological history of the region.

The canga in some localities appears to have been broken up and transported, now occurring as rubble in the red surface deposits as between São Pedro de Itararé and Fabio Rego. In this case the canga must have been segregated prior to the transported red earth, and if the red deposit be assigned a Pleistocene date the canga may be referred to the Tertiary.

The decomposed state of the rocks in Brazil was early recognized and correctly described by José Bonifacio de Andrada e Silva and Martim Francisco Reibeiro de Andrada in an account of a mineralogical journey from Santos to the tableland made in 1820. This article is reprinted in Ferreira's Diccinario geografico das Minas do Brazil. Rio de Janeiro, 1885, p. 341, 342.

Weather-blocks.— The weathering of the granites along the coastal slope of the Serra do Mar has led to the production of thousands of rounded weather-blocks which are particularly evident at the present sea-level and just above within the zone of wave action, those above the present sea-level having had the fine material between them removed in part at a time when the land stood a few feet lower than it now does. Abundant examples are to be seen about the shores of Rio Harbor. The illustration, Plate **2**, is from a photograph of a group of blocks on the shore of São Francisco Harbor in Santa Catharina. In Madureira, a suburb of Rio de Janeiro, near Cascadura Station there is fine large block said to be movable (pedra movediça) poised high up on a weathered tower of granite. The famous Furnas de Agassiz at Tijuco in the Serra near Rio de Janeiro is another group of weather-blocks, the most imposing to be seen anywhere in south Brazil.

It remains to note certain rock benches and the uplifted fringing coastal plain to be seen along the shores from Rio de Janeiro to near Laguna on the south.

From observations made about São Francisco Bay in latitude 26° S. I suspect that there exists along this coast an old bench of marine erosion 150 or more feet above the present sea-level. Numerous rock

islands along the coast at variable distances from the shore rise to nearly this height and about São Francisco Bay well in back of the town there are low foot hills separated by valleys from the base of the Serra and from each other, and similar hills confront the somewhat higher ones at the south side of the entrance. Presumably this

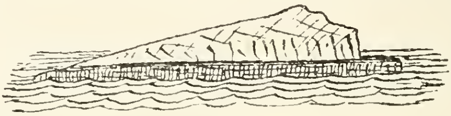

FIG. 33.— Terrace about islet in the sea north of Laguna, Sta. Catharina.

dissected rock bench is of very ancient date, early Pleistocene or Tertiary.

A more recent set of rock benches form narrow platforms about many rock islands along this same extent of coast apparently standing from eight to ten feet above sea-level. They agree closely in level with the alluvial plains bordering the bays. Figure 33 gives the outline of such a terrace skirting the base of a small rocky islet north of Laguna as seen from a steamer. Hartt (1870) has given abundant evidence of a recent uplift of the coast to this height. This change of level is seemingly very recent.

Between the first described signs of a very ancient bench, and this recent uplift must be interpolated an episode of subsidence carrying the sea into the valleys at the base of the Serra do Mar. The harbors, great and small, are due to this change of level. The filling up of the harbors and river channels and the building of an underwater deposit makes an estimate of the depth of this depression too small but as the harbor at Rio de Janeiro has a maximum depth of 30 M. (Hartt, 1870, p. 7) the sinking must have been equal to this depth plus the amount of the recent elevation.

On the flats east of Paranagua there is a well-defined low beach ridge covered with dead shells of Ostrea and a smaller gibbous lamellibranch at an elevation of eight or ten feet above sea-level and separated from the shore of the bay by two flats at slightly different levels. The shells are not worn; some of them have both valves in position. The situation of the deposit and the mode of occurrence of the shells is very different from that of the accumulation of shells left by aborigines on neighboring sandy deposits.

Geographic Control of Human Occupation.— The effect of the several geographic features above outlined on the human occupation of

south Brazil are more or less patent to every visitor. The dissection of the coastal slope and the depression of the resulting Serra do Mar has given rise to commodious harbors so uniformly wanting because of the unlike geological structure and form on the west coast of South America. But the Serra do Mar renders ingress to the country exceedingly difficult and possible for roads and railways only along certain routes. Back of the Serra do Mar for the most part the lands slope toward the interior of the continent, and the large rivers, navigable by small boats, serve only with ease to carry commerce into the interior. The transportation to the coastal border of the plateau is everywhere upgrade making the export of the products of plantations and the forest more costly than the importation of foreign goods, an item of cost which is offset on the inward journey by the necessity of ascending the Serra do Mar, and, to reach the trap plateaus, of surmounting the Triassic escarpment. Transportation is naturally slow to develop, except where peculiar conditions, such as give rise to the rich coffee-fields of São Paulo, have repaid the construction of railways.

The recently uplifted plains of alluvium bordering the harbors afford the sites for the first settlement of the sea-coast. The variable relief of the dissected front of the Serra do Mar furnishes stations for residence at altitudes great enough for Europeans, whose affairs require their daily presence in the federal capital, to escape the languishing effects of a continuous abode in the hot zone at sea-level, but the way to these retreats calls for special and costly methods of transportation, as in the case of the route to Petropolis. Owing to the mountainous relief of the coastal slope of the Serra do Mar and the luxurious growth of tropical vegetation the inhabitants enjoy outlooks unsurpassed in any land. As a scenic route for the traveller the railway journey from Paranagua to the summit of the Serra through the defile of the Ypiranga is surprisingly pleasant, and at many points exciting.

The contrast between this region and the surface of the plateau is striking. The tableland is the seat of production. Variations in the geological character of the surface modified by altitude and rainfall come sharply into play. In northern São Paulo and adjoining parts of Minas Geraes the soils known as *terra roxa* and *terra vermehlo* developed by decomposition of the trap sheets which invade the Permian terrane afford under the peculiar conditions of rainfall there existing the richest coffee-fields in the world. Farther south the Devonian and Carboniferous sandstones present less favorable conditions. Open campos or prairies characterize much of the region underlain by Palaeozoic strata.

Much has been said as to the origin of the treeless condition of this region. About Ponta Grossa in Paraná the persistence of the elements of the forest along the brooks and rivulets and near the water courses would seem to point to the oft repeated supposition of a diminished rainfall following the glacial period as the probable cause. In my notes on the surface deposits I have presented some reason for thinking that traces of such a change in the rainfall and run-off are observable.

In Paraná and Santa Catharina farming and cattle raising find suitable conditions and here the influx of European settlers from Germany, Poland, and in Rio Grande do Sul from Italy, has under the more temperate climate of the upland wrought commensurate changes in the appearance of the country.

Mention has already been made of the harborage to lingering remnants of hostile natives which the Triassic trap escarpment affords. Farther in the interior larger bodies of aborigines favored by the unnavigable rivers made inaccessible from their lower courses by reason of the numerous falls over the trap sheets maintain to a large degree the primitive state of the Brazilian highland.

VIII. NOTE ON THE CHANGES OF LEVEL OF THE COAST OF SOUTHERN CHILE.

For more than seventy years Darwin's raised beaches and terraces of the west coast of South America have been generally regarded by English-speaking geologists as typical examples of a relative change of level of land and sea. Sir Charles Lyell by embodying the observations and conclusions of Darwin in his classic Principles of geology gave wide distribution to the views of Darwin concerning the magnitude and extent of the supposed recent elevation of the west coast of South America. A dissent from the views of the justly celebrated naturalist of the "Beagle" was scarcely heard in geological circles until in 1885, when Edouard Suess brought out *Das Antlitz der Erde,* in which work he sought to show by testimony mainly that of observers of the Chilean coast since Darwin's voyage, that no noteworthy elevation of this coast in recent times had taken place. Upon the publication of the French translation of Suess's great work, La Face de la Terre, the writer (J. B. Woodworth, 1898, p. 803–806) in a review expressed a disbelief in the sufficiency of the evidence brought against Darwin's observations and conclusions. In fact, I went to Chile rather for the purpose of studying the nature of the movements, whether by frac-

ture and faulting or otherwise, which must have attended this supposed elevation, than to confirm or refute any conclusion as to the elevation of the coast at a time so recent as that embraced within the period of elevation of beaches, so well established in the Champlain or Hochelagan marine district of northeastern North America. The following notes and conclusions thus have the force of being made with a pre-

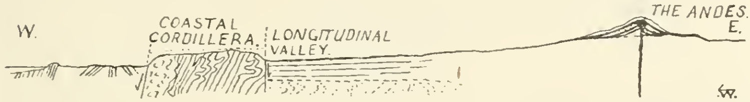

Fig. 34.— Diagrammatic cross-section of southern Chile west of the Andes. Based on Pissis and personal observation in the longitudinal valley and Coastal Cordillera.

conceived opinion quite opposite in most respects to the judgment which in the sequel I was obliged to make. But the geological structure bearing on changes of level should be first set forth.

The geological structure of Chile south of Valparaiso is in its broad outlines readily grasped in such a rapid reconnaissance as I had the opportunity to make. The main facts were clearly outlined by Pissis (1875) from whose work and my own observations the following brief introduction will serve to make clear the relations of the Coastal Cordillera with its frequent earthquakes, and the chain of the Andes lying back from the coast.

In south Chile for a great distance north and south there are three well-defined topographic and structural zones, viz.: — the Andesian folded chain with volcanic vents, the Longitudinal Valley confronting the chain on the west, and the Coastal Cordillera forming the coast. These three differently constituted areas are shown diagrammatically in the subjoined cross-section, Fig. 34.

The formations which enter into this section were roughly determined by Darwin (1891) as follows: —

Darwin's scheme of geological formations in Chile.
(Compiled from "Geological observations.")

Newer Tertiary, including the basin-plains of Chile.	Superficial saliferous deposits of Iquique. Salt and nitrite of soda, 3,000 ft. above sea-level. Beds of gravel, red sandy clay; lava, pumice beds, overlying calcareous tufa.
Concepcion formation.	Sandstones with lignites, silicified wood, and "concretions" carrying marine shells. Eruptions.
Upper Cretaceous?	Tuffs and submarine lava of Uspallata section; conglomerates of valley of Tenuyan. Upheaval in central Chile forming Cumbre and other ranges.
Cretaceo-Oolitic; Gypseous formation.	Coarse conglomerates, siliceous sandstones, dark mudstones, limestone, pseudohornstones, tuffs, and vast beds of gypsum, with marine fossils and silicified trunks of fir-trees at Los Hornos. Eruptions of purplish claystone and greenstone porphyries, etc.
Metamorphic series.	Metamorphic schists, plutonic rocks, and more or less altered clayslate.

The more recent work on the geology of Chile has been summarized by Mr. Lorenzo Sundt (1909, p. 37–44). According to this geologist, the sedimentary formations now recognized in Chile are as follows: —

Geological formations of Chile, mainly from Sundt.

Pleistocene.	Eolian and other deposits of Atacama on the north. Glacial till and gravels in the south.
Eocene.	Conglomerates and sandstones. Lignitic group of Coronel.
Cretaceous.	Sandstones of Quiriquiña Island, and along the coast. Conglomerates, sandstones, and black calcareous, fossiliferous shales of Coquimbo and the Pequenes Range.
Jurassic.	
Triassic	Not recognized.
Sub-Carboniferous or Upper Devonian.	Fossiliferous beds at mouth of the Rio Choapa.
Devonian or older.	Metamorphic series; mica schists of Coastal Cordillera south of Caldera.

The Andes consist of deformed, squeezed up, and dissected beds of the Tertiary and older rocks, with eruptives. The Longitudinal Valley comprises Tertiary and possibly older beds overlain by lavas and Pleistocene gravels the preglacial members of which series apparently dip gently westward until cut off by the eastern fault of the Coastal Cordillera. The Coastal Cordillera, made up of the metamorphic series and granite intrusions, is fringed by Cretaceous and Eocene deposits in faulted relations with the older terrane.

The Coastal Cordillera forms a long narrow tableland parallel to the coast with an elevation from 1,200 to 1,500 feet, the flattish upper surface of which is evidently a peneplain from which more recent beds

have been denuded. These beds appear to have been the same Cretaceous and Tertiary strata which occur in patches along the coast in dislocated positions. The borders of the Coastal Cordillera are determined by faults so that the Cordillera is itself a long relatively uplifted fault-block or "horst." Relative to it, the western side of the Longitudinal Valley on the east has sunk as has also the Pacific Ocean border on the west. It is along the fault-zone on the west, partly if not altogether, that the epicenters of great Chilean earthquakes mainly lie as was the case with that of Coquimbo in 1906, which destroyed Valparaiso and neighboring towns.

It follows from this structure of the west coast of South America throughout the greater part of Chile that the earthquakes which take place along the faulted edges of the Coastal Cordillera arise from the movements of this horst and are not directly connected with the folded chain of the Andes on the east. Accepting as I think we must the essential accuracy of Darwin's and Fitzroy's observations upon the elevation of the coast about Concepcion at the time of the earthquake of 1835, it does not follow, however, as Darwin thought, that the Andes were simultaneously elevated.

In the Valparaiso earthquake of 1906 Professor Steffen has found evidence of a local elevation amounting to half a meter on the western border of the Cordillera at that place; but it is a question whether the elevations which take place at the time of these earthquakes are permanent. At Concepcion it is the opinion that a subsidence follows the uplift of the coast. Nevertheless the horst stands as an indubitable block of evidence of uplift in relation to the ocean bottom and the Longitudinal Valley.

The date of beginning of the faults which bound the horst of the Coastal Cordillera is Post-Eocene and apparently late Tertiary. Whether movement has taken place in modern times along the fault on the east I am not able to say. The Pleistocene gravels at San Rosendo abut against the horst without signs of disturbance; and the rivers, such as the Bio Bio, Calle Calle, and Maule, have cut channels across it on their way to the sea from a superposed position. Neither the Rio Bio Bio nor the Calle Calle, through whose valleys I passed in traversing the width of the horst, display rapids such as might be due to recent uplift at a greater rate than that of the cutting power of these streams to maintain a free grade to the sea.

It seems most probable that the eastern fault bounding the Longitudinal Valley is of early Pleistocene or late Pliocene date, and that the present valley is due to erosion of the lavas and sediments *pari passu* with the cutting of the gorges.

If one reads Chapter X on the Plains and valleys of Chile in Darwin's Geological observations, he will find the author convincing himself that the sea rather than the rivers now coming out of the Andes is accountable for nearly every detail of the land form,— not only the passes in the mountains and the valleys sculptured in the mountain mass but also the plains of waterworn detritus particularly where rounded pebbles are found.

This statement tallies with the general belief of the school of geologists of the period in which Darwin formed his concepts. It was naturally easy for him to admit terraces of any origin and marine shells on the surface at lower levels along the coast of Chile as evidence of elevation when he had found to his own satisfaction that the sea had beaten against the high Andes where no recent marine shells are found. This much is necessary for the reader to understand in weighing the conclusions which may be presented concerning the elevation of the coast of Chile.

It is only just to Darwin, however, to show from his own writings how he abandoned the views he entertained concerning topographic signs of elevation on the coast of South America when in later years similar problems came to his attention in the British Islands.

Darwin (Francis Darwin, 1903, **2**, p. 191) wrote Lyell in 1861,— "I return Jameson's capital letter. I have no comments, except to say that he has removed all my difficulties, and that now and for evermore I give up and abominate Glen Roy and all its belongings. It certainly is a splendid case, and wonderful monument of the old ice period . . . . How many have blundered over those horrid shelves!"

Again in 1868, Darwin (Francis Darwin, 1903, **2**, p. 211) wrote Croll,— "I was formerly a great believer in the power of the sea in denudation, and this was perhaps natural, as most of my geological work was done near sea-coasts and on islands.

"But it is a consolation to me to reflect that as soon as I read Mr. Whittaker's paper on the escarpments of England, and Ramsay and Juke's papers, I gave up in my own mind the case; but I never realized the truth until reading your papers just received. How often have I speculated in vain on the origin of the valleys in the chalk platform round this place, but now all is clear." Still he clung to his interpretation of terraces and of shells on the surface in South America. As late as 1872, Darwin wrote Lyell (Francis Darwin, 1903, **2**, p. 164–165),— "It seems to me very cool in Agassiz to doubt the recent upheaval of Patagonia, without having visited any part of it; and he entirely misrepresents me in saying that I infer upheaval from the form of the land, as I trusted entirely to shells embedded and on the surface.

"It is simply monstrous to suppose that the terraces on a dead level for leagues along the coast, and miles in breadth, and covered with beds of stratified gravels 10 to 30 feet in thickness, are due to subaerial denudation."

Darwin seems here to have forgotten what he wrote on the shells embedded in a friable calcareous rock in the terraces of Coquimbo at a height of 250 feet. "Although I examined so many hundreds of miles of coast on the Pacific, as well as Atlantic side of the continent, I found no regular strata containing sea-shells of recent species, excepting at this place, and at a few points northward on the road to Guasco. This fact appears to me highly remarkable; for the explanation generally given by geologists, of the absence of stratified fossiliferous deposits of a given period, namely, that the surface then existed as dry land, is not here applicable; for we know from the shells strewed on the surface and embedded in loose sand or mould, that the land for thousands of miles along both coasts has been lately submerged." (1845, p. 344.)

The interpretation of the shells strewed on the surface and embedded in the loose sand or mould constitutes the essential difference between Darwin's hypothesis of their marine deposition and the theory that such surficial deposits pertain to the group of kitchen-midden.

My own observations of the coast of Chile were made about Corral and Valdivia in latitude 40° S., at Talcahuano and Concepcion, in latitude 35° 35′ S., and with less scope about Valparaiso in latitude 33° S.

The Coast at Corral and Valdivia. Of Valdivia, Darwin (1891, p. 236) states "I did not observe any distinct proofs of recent elevation; but in a bed of very soft sandstone, forming a fringe-like plain, about sixty feet in height, round the hills of mica-slate, there are shells of Mytilus, Crepidula, Solen, Novaculina, and Cytheraea, too imperfect to be specifically recognized."

The plain or rather terrace which Darwin mentions extends from the open coast outside of Corral entrance (Plate **29**), about the sides of the harbor of Corral and up the Valdivia River to the city of that name. It is well shown about the sides of Manzera Island in the harbor of Corral (Plate **30**), and is a distinct feature along the banks of the Valdivia River (Plate **31**). It is a terrace of denudation sometimes cut in the soft Tertiary sandstones mentioned by Darwin, sometimes in conglomerates as at Corral, and sometimes in the schists. About Valdivia and Teja Island this terrace I estimated to be fifty-five feet above the sea-level and the same along the Rio Cruces Channel. The

same level holds for the seaward edge of the terrace on the south side of Corral entrance facing the open sea, where, however, the surface rises inwards towards the hills, being in part covered by deposits at the mouths of gullies. The terrace thus has the appearance of being a few feet higher on the coast than inland. At most, the terrace is a few rods in width and carries here and there a few houses. On the south side of Corral entrance near English Bay, there are drongs, or stacks of the schists standing up on the surface of the terrace, evidently sea-stacks left by marine erosion at about the sixty foot level. I saw none of these along the Valdivia River or inside of Corral Harbor. I have no doubt that this bench marks a stand of the sea when the coast stood relatively lower than now. Above this terrace the hills are sharply ravined by long continued sculpturing of the schists and no signs of beaches or wave action were found. The next higher plain is that of the summit of the Coastal Cordillera (Plate **29**), which is undoubtedly an old peneplain of Tertiary or older date.

The lack of beach deposits or signs of modern occupation of the fifty to sixty foot terrace by the sea makes it necessary to place its origin in early Pleistocene or possible Pliocene times. It is long anterior to such beaches as occur about the shores of the Champlain or Hochelagan sea in northeastern North America.

South of Corral entrance near a group of houses I saw marine shells on the terrace in the sod but they were in such a situation as to render it altogether probable that they had no geological significance, being nothing more than refuse of the aborigines.

At Valdivia and Corral it seems to me demonstrable that there was in early Pleistocene of late Tertiary times a relatively lower stand of the land than now by about sixty feet during a period long enough for the river to widen out its valley on a rock-floor of schists and older Tertiary sediments in a disturbed position. Whether these Tertiary sediments occupy an old valley in the schists or owe their position to down-faulting I can not state from the observations which I made. Their disturbed attitude and the presence of cleavage in the conglomerates at Corral favors the view of infolding and down-faulting of the Tertiary beds in the schistose terrane. After this period of partial baselevelling the land rose about sixty feet relatively to the sea.

The presumption that the channel of the Valdivia River and the depression forming Corral Harbor have been excavated since the uplift of the terrace began is also an argument for the ancient date of the sixty foot terrace. The depths of water in the Valdivia River

and connecting channels vary from forty-eight to ninety feet and depths of seven and eight fathoms occur in the Rio Valdivia opposite the town. While glacial gravels and boulders not far inland as at Llanco Station show the presence of Pleistocene glaciers or glacio-natant waters, I noted no distinct signs of glacial erosion of the channels about Valdivia. It seems to me more probable, therefore, that these depths indicate a depression of the coast since the formation of the terraces rather than that they are due to glacial erosion independently of the sea-level.

Below the fifty-five to sixty foot level, I noticed a small terrace on Teja Island opposite Valdivia at a height about twenty-five feet above sea-level, but this was not elsewhere observed except possibly as noted below.

Along the coast south of Corral entrance near Palo Muerto Pt., there are several ancient sea-caves not now visited by the sea at high tide. Near them is a trace of a bench at about 22 feet. The mouths of these caves are not over ten feet above sea-level (Plate **33**). The bottoms of the caves are covered with a fine dusty cave-earth which covers any pebble bed which may occur on their bottoms. One of the caves (Plate **33**) had been at the time of my visit recently occupied by natives and a heap of shell refuse formed a considerable mound at the entrance. In the same vicinity at Morro Gonzales there is a natural bridge in the rock of the sixty foot terrace formed by a cave penetrating to a small ravine in the rear. In front of the caves at a few points where the coarse Tertiary conglomerate is developed there is a flat or bench, cut back across these rocks, whose surface is at least partly covered by high tide. It is evident that a slight relative rise has taken place removing the caves from the action of the sea, but while this may have been as much as ten feet it may not have been over five feet as the depth of cave-earth would seem to show. In embayments south of Corral entrance, there are old beach ridges the highest of which comes sharply against the ravined surface of the land behind it. The uppermost of these ridges agrees well with the level of the mouths of the caves and does not indicate a rise of more than ten feet and possibly not more than five feet above sea-level; but, as Suess has pointed out, on the west coast of South America beach ridges may be thrown up by seaquake waves or *tsunamis* above the normal marine limit and thus are to be taken with caution.

At Talcahuano and Concepcion. The literature concerning elevation about the Bay of Concepcion relates largely to the discussion

concerning the change of level accompanying the earthquake of 1835. As Darwin noted, little or no evidence of the elevation claimed by him and Fitzroy could be seen by a subsequent visitor. The Old Fort at Penco (Old Concepcion) is shown in Plate **4**. The alleged evidence of elevation prior to this famous incident pertains largely to marine shells found on the hills about the Bay of Concepcion. Another feature which undoubtedly is the result of relative uplift of the land is the alluvial plain upon which the modern city of Concepcion stands.

Ulloa (1772, **2**, p. 252–254) who visited Concepcion Bay as early as 1744 describes the occurrence of shell deposits from six to twelve feet and more in thickness within four of five leagues from the shore and also on the tops of hills fifty toises (320 feet) high. He mentions seeing one deposit at a height of twenty toises.

Darwin (1887, p. 310) speaks of "the vast number of sea-shells scattered over the land, up to a height of certainly 600, and I believe," he states, "of 1000 feet." He appears to have entertained no doubt that these shells were evidence of an elevation of a former sea-bottom to these heights as explaining the occurrence of the shells.

The shell deposits described by Ulloa in the plain about Concepcion, though I did not see them, presumably are in their natural site as they form a part of the tilted plain of the "Formation of sand and shells" described by Pissis. This plain at Concepcion I estimated by aneroid to be forty-five feet above sea-level. Westward towards Talcahuano there are successive lower levels, that at the golf links I made seventeen feet, and the next lower level adjacent to the bay of Concepcion about ten feet. The surface has been more or less modified by the blowing of sands by the winds. I saw several boulders in the upper dark stratified sands of the plain between Concepcion and Talcahuano along the railway cuts. One of these blocks was eighteen inches in diameter. These boulders were in an embedded position and would seem to demand floating ice for their transportation. It is to be presumed that the water-laid portions of the deposits are therefore of Pleistocene date.

Back of Concepcion the plain of sand abuts against the base of the Coastal Cordillera at the hill called Cerro Caracol. I searched in vain for any definite beach along the upper limit of the plain, but stream-action would long since have obscured such local deposits at this juncture. Above this level to the top of Cerro Caracol the granitic rock displayed only evidences of long continued atmospheric weathering and the vertical lines of dissection worked out by running water. Nowhere did I observe signs of the Pleistocene stand of the

sea much above the level of the plain. A small cave in the granite of the hillside in the public park by its angle of slope into the rock is shown to be artificial and having nothing in common with sea-caves.

A visit to Penco on the north of Concepcion gave little or no evidence regarding a change of level. The plain of dark sands is here wanting, that deposit being largely an ancient delta of the Rio Bio Bio. At the north end of Penco Beach, on a point of rock cut off by the railway cut from the bluff of Tertiary sandstones which here form the shore, at about twenty feet above sea-level I found shells thickly strewn in the soil together with fragments of mammalian bone, a typical mode of occurrence of Indian shell-heaps.

Talcahuano and Tumbres Peninsula.— I have given some account of the coast near Tumbres Peninsula in my itinerary (p. 32). There are good sea-caves on the inside of the Paps of Bio Bio at the present sea-level but none above. The surface of the Tumbres Peninsula is covered with a brownish weathered layer containing chips of quartz and schist derived from the underlying rock. Waterworn pebbles are absent except in situations about to be described as village sites. There are sloping surfaces of the bed rock at discordant levels and abundant traces of water action in cutting vales, but none of the horizontal lines marking the prolonged action of waves in cutting cliffs or heaping up beach materials.

On the southeast side of Tumbres at about 330 feet I found round patches of marine shells in the sod of the tosca or surface deposit. The shells in the first example seen occupied a space about twenty-one feet in diameter in which the grass, in December, of a light color because it was dead, showed clearly the shell covered area because all about the shell tract a species of sorrel with a reddish stem and fruit grew in abundance. This plant avoids the shell deposits probably because of the lime. Observing this character of the vegetation, I went to other tracts which from a distance showed the absence of the sorrel and found them in each case the site of a thin shell deposit. One of these shell deposits was upwards of forty feet in diameter. In one of these areas I picked up a stone pestle, a cylindrical beach pebble battered by wear at both ends. With the shells were a few broken beach pebbles which seemingly could have had no use, but such pebbles were altogether absent in the weathered soil and tosca rock outside of the shell deposits. It is evident that these deposits are of human origin. Darwin mentions shell deposits on Sentinella Hill at about 400 feet elevation reported to him by Dr. Jenks, the Assistant surgeon of the Beagle. At no point on the peninsula was I

able to detect anything like Pleistocene beaches or the work of waves at elevations above that of the plain of Concepcion and this plain is practically the only evidence of a former stand of the land lower than the present sea-level since the time of the Tertiary and older deposits which contain marine fossils.

Darwin was familiar with the fact that the natives carry large quantities of shell-fish inland, but in commenting on the fragments of shell-bearing forms such as sea-urchins found several miles inland from the coast he doubted the human origin of many deposits on the ground that it was improbable that the natives would transport such materials to any distance from the coast. On the contrary, it is well known that sea-urchins are an article of food in Chile. I saw in the market at Tamuca baskets of a large sea-urchin with the spines attached. The natives use for food many shell-fish which the unnaturalized European does not think of utilizing and if one objects that in the Pre-Columbian days such stores of food would decay in the course of a distant inland journey due allowance must be made for savage tastes. The "hung" meats and festering cheeses of civilized countries show how much latitude must be allowed for aberrant tastes. In the semi-arid and arid climatic zones of the Coastal Cordillera many Mollusca would become dessicated rather than putrid because of a belated consumption. In fact the unusual distance to which shell accumulations are found back from the coast of Chile appears to me quite compatible with the physical environment of an aboriginal people whose hinterland in the Longitudinal Valley was in primitive times less fruitful than the adjoining sea. Kitchen-middens occur here in every degree of accumulation from the now sparsely scattered shells in the sod marking a temporary abode to the thick shell-heap on the site of permanent habitations. Shells on the surface or buried in the superficial subaerial deposits along this coast are no more a criterion of submergence beneath the sea than elsewhere and cannot be relied upon as proving anything other than the agency of man.

The Red Soil.— Along the western slopes of the Coastal Cordillera there are large tracts with a red soil, the characteristic effect of the subaerial decomposition of rocks. The situation of these residual deposits, the nature of the topography without beaches or marks of wave action, and the abundant traces of the secular leaching by rains and moisture, together with the gullying of the ancient surface on which these deposits occur, alike bespeak ordinary atmospheric processes as conditioning the formation of this red earth. The occurrence of shells and other exuviae in this deposit is but an indica-

tion of man's occupation of the area for a few centuries perhaps in the past.

Pissis (1875, p. 78–81) has described the distribution of the most recent marine elevated deposits of Chile. Beginning on the north in the plain which extends from the Bay of Antofogasta to that of

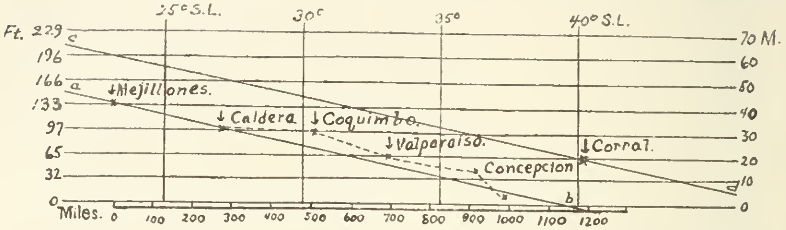

FIG. 35.— Rise to the north of the Recent uplifted marine deposits of Chile, according to the data of Pissis (1875, p. 78–81). The dotted line shows apparent warped surface from Caldera southward. The line a–b gives the mean tilt-rate from Mejillones southward. The line c–d is drawn at the same tilt-rate to touch the elevated rock bench at Corral.

Mejillones this plain, having there an altitude of forty meters, is represented by correlated deposits at constantly lower levels on the south as far as the 38th parallel. In the vicinity of Caldera the deposits rise from twenty-five to thirty meters above sea-level. About Valparaiso and San Antonio the level is maintained between fifteen and twenty meters. The city of Concepcion is built on the sands at the mouth of the Rio Bio Bio and finally at Levau the deposits rise scarcely two to three meters above the sands of the beach. Taking these data as given by Pissis and plotting the upper limit between Mejillones and Levau, the tilt-rate is shown by the graphical construction in Fig. 35. According to these observations made by Pissis as early as 1875 the coast from a point north of Valdivia shows a rise at the rate of about 0.13 ft. per mile for about 1,100 English statute miles.

Valdivia and Corral lying to the south of this group of raised deposits as noted above shows evidence of depression preceding the last slight rise of the coast. Accepting Pissis's altitudes for the height of the uplifted plain and assuming the above rate of tilting, the abandoned sea-caves south of Corral fall on a tilted plane about three meters above that of the formation of sands and shells, and may tentatively be regarded as at the sea-level under which the sands were laid down.

The fifty-five to sixty foot bench at Corral is at that place about fifty feet above the line of the abandoned sea-caves. What the attitude of this terrace is south of Corral I am unable to state. That the depression of the coast continues increasingly southwards is possibly indicated by the extensive fiord zone however much these channels may have been over-deepened by the Pleistocene glaciers. But Darwin's (1891, p. 233) account of sea-caves not now visited by the waves on the island of Chiloe, though these small caves may be more recent than those of Corral, shows the necessity of a resurvey of this coast before assuming any uniform rate of tilting over great distances.

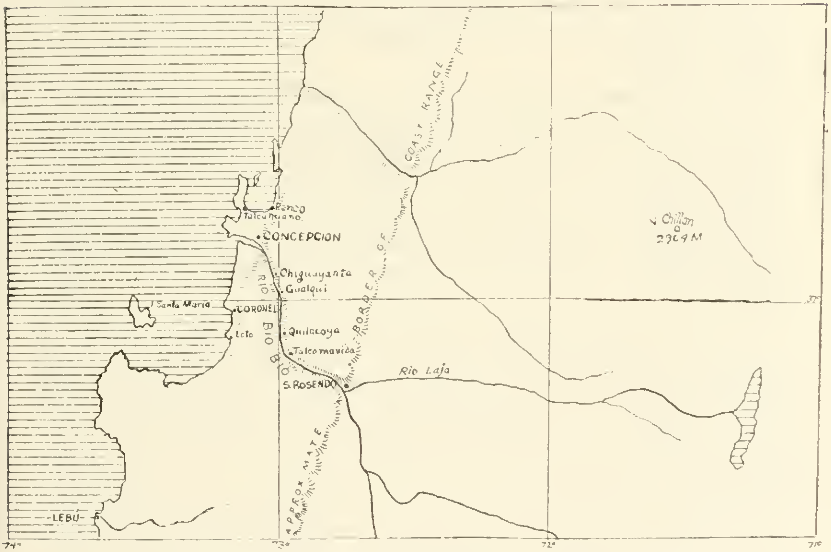

FIG 36.— Sketch map of country about Concepcion, Chile.

Terraces of the Rio Bio Bio within the Coastal Cordillera.— From the delta plain of the Rio Bio Bio at Concepcion there is a series of river terraces within the cañon of the river rising in altitude to San Rosendo at the border of the Longitudinal Valley. The railway from Talcahuano to San Rosendo follows the river, rising at a very uniform grade now on a lower terrace and again passing through cuts in the margins of a higher terrace. The following notes were taken on a railway journey from Concepcion to San Rosendo. The elevations of the

railway stations and distances from the terminus at Talcahuano are from the official map of the railways of Chile. The estimates of the elevations of the terraces are approximate only except at San Rosendo where measurements were made with an aneroid barometer.

Talcahuano, O. kms. Altitude 3 M. (9.8 ft.). This is the elevation of the border of the delta of the Rio Bio Bio.

Los Pexales, 7 kms. alt. 6 M. (19.6 ft.). This is a point on the plain midway between Talcahuano and Concepcion.

Concepcion, 15 kms., alt. 9 M. (29.5 ft.). This is the elevation of the railway station near the river. The plain rises north of this point to an elevation of about forty-five feet.

Chiguayante, 25 kms., alt. 18 M. (59 ft.). This Station is within the gorge where the river flows northwest. Above this point a stony terrace appears.

Gualqui Station, 38 kms., alt. 21 M. (68.8 ft.). Terraces of alluvium judged to rise from thirty to thirty-five feet above railway, or 100 feet above sea-level. At about 120 feet above sea-level there is a sloping dissected terrace in the decomposed bed rock of the gullied sides of the cañon. The fine sand deposit continues as a terrace bordering the river, apparently a continuation of the deposit forming the Concepcion Plain. Above this terrace the side walls are deeply gullied.

Quilacoya Station, 48 kms., alt. 25 M. (82 ft.). The terrace here rises to about 105 feet above sea-level, at its edge. The railroad runs on a deposit of the dark sands. Old rock remnants of a sloping terrace are to be seen on the ravined walls of the gorge, apparently indicating an old baselevel of the river before noted as visible above Gualqui Station.

Talcamavida Station, 62 kms., alt. 34 M. (111.5 ft.). The fine dark sands form a terrace rising twenty to twenty-five feet above the Station or about 130 to 135 feet above sea-level. The general trend of the gorge from this point to San Rosendo is southeast. Above this Station in the terrace large angular stones, cobbles, and gravel appear, indicative of flood conditions with ice-rafts,— typical glacial river deposits.

Gomero Station, 69 kms., alt. 38 M. (124.6 ft.). The edge of the terrace is here about twenty feet above the railway, or about 145 feet above sea-level. Heavy gravel beds are exposed along the river above this point, with waterworn cobbles.

Bunaraqui Station, 76 kms., alt. 41 M. (134.5 ft.). Top of terrace about twenty feet higher, or about 155 feet above sea-level.

Malvoa Station, 79 kms., alt. 43 M. (141.0 ft.). Good terrace on opposite or southwest side of river. At railway station there are clays.

San Rosendo Station, 85 kms. alt. 46 M. (154.8 ft.). East of the Station there was in 1908 an excellent exposure of gravels and sands in a deep cut, rising about sixty-five feet above the railway, or to an elevation of 220 feet above sea-level. The annexed section is from a drawing made on the spot. (Fig. 37).

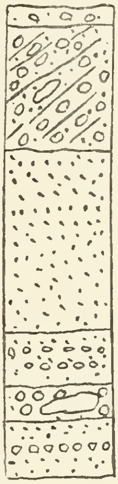

Fig. 37. — Section of Pleistocene terrace at San Rosendo, Chile, in 1908.

This section reveals a succession of river deposits varying from sands like those now transported in this portion of its course by the Rio Bio Bio to coarse gravels including large boulders such as demand ice-rafts or the proximity upstream of glacial conditions.

The lowest bed exposed (see Fig. 37) consists of dark sand with pebbles of a volcanic rock. Above this comes a coarse gravel including a boulder of gneiss about seven feet long. Next in the section is sand with thin bands of volcanic pebbles. Above these layers comes about twenty-five feet of dark sands with a thin band of volcanic pebbles. Surmounting this and forming the surface is a layer, about twenty-feet thick, of coarsely bedded gravels and boulders, the cross-bedding of which suggests the structure of a delta front.

There are in this section thus the records of two episodes when the river transported to this point coarse gravels and boulders which it is to be presumed indicate contemporary advances of the local glaciers or times of unusual melting and discharge of coarse débris.

I saw no marine shells in any part of this terrace or on its surface, and no evidence of the presence of the sea in the deposition of the materials. The structure is quite like that of many glacial river deposits in the inland portions of glaciated North America. The lower bed of coarse gravel with boulders must have been deposited at or above sea-level as is also the case with the uppermost bed of like materials. The aggradation of the valley under glacial stream-action affords a simple explanation of these deposits without recourse to the hypothesis of a change of level in relation to the sea.

This section is the most reliable in its bearing on the altitude of the terraces, since those lower down the river were estimated only from

the elevation of their edges as seen from the train and the tops of such terraces may rise higher than the figures above given. From Concepcion at the seaward mouth of the gorge to San Rosendo along the river is a distance of 70 kms. (42.7 miles). Taking sea-level in Pleistocene time at Concepcion as forty-five feet, the San Rosendo terrace gives a uniform rise up the river of 4.3 feet per mile for the grade of the river, not in the least too steep to be within the range of streamaction for the entire distance above Concepcion. It does not appear to me therefore that the terraces of the Rio Bio Bio within the Coastal Cordillera demand a lower stand of the land than is indicated by the delta plain at Concepcion.

The traces of a higher floor of the valley shown in the faint rock-terraces within the gorge of the Bio Bio are of very ancient date. They appear to be more deeply dissected than the rock-bench at Corral with which it would be hazardous to correlate them. The tops of the low hills of Tertiary rocks piercing the plain at Concepcion are possibly nearer the level of the Corral bench, but these and other questions concerning ancient changes of level of baselevelled rock surfaces on this part of the coast of Chile await further study. I am only able to state that as the result of my own observations it appears that an elevation since late Pleistocene times has taken place at Concepcion amounting to something like forty-five feet; that at Corral and Valdivia an older Pleistocene or late Pliocene uplift of about sixty feet is indicated, and that a recent uplift of a few feet not more than ten and perhaps not more than five feet is indicated, and that, in conclusion, the coast of Chile affords a largely open field for the determination of the changes of level which it has undergone in relation to the sea during Pleistocene and late Pliocene times, involving a thorough revision of Darwin's studies on this subject in the light of criteria which were not in his time applied to the study of shorelines.

IX. STONE IMPLEMENTS AND POTTERY FROM LAGUNA.

By R. B. Dixon.

A number of specimens from an aboriginal camp-site near Laguna, Province of Santa Catharina, have been placed in my hands for description, by Prof. J. B. Woodworth. The specimens comprise stone implements and pottery sherds. The stone objects are of three varieties, (1) hammer-stones, (2) smoothing-stones, (3) and celts.

The hammer-stones are of a simple, world-wide type, slightly pitted on two sides where held between the thumb and fingers. The smoothing-stones are from two to three inches in length, and show on one or more sides evidences of rubbing and polishing. They were in all probability used in the manufacture of pottery, for smoothing the irregularities of the surface, both inside and out. The celt is of basalt, having a length of a little over six inches, with a width at the cutting edge of two and a quarter inches, and tapering somewhat toward the butt. One side of the implement shows somewhat greater convexity than the other and the entire surface was finished by grinding.

The pottery sherds collected represent four somewhat different types. The first of these is a smooth, reddish ware, undecorated, and with a thickness of three eighths of an inch. It was apparently used for bowl-shaped vessels of rather small size. A second type is a very coarse, red ware, from one half to five eighths of an inch in thickness. The broken quartz and gravel used for tempering is extremely coarse. The surface of the vessels was covered with thumb-prints, often of large size, where the coils had been pressed together in the process of manufacture. The vessels were probably of large size. A third type of sherd shows a heavy and rather coarse gray ware, the surface covered by a buff or yellowish slip. This ware is nearly an inch in thickness, and the smoothed surface is decorated by painted designs in red. The figures are rectilinear, and seem to be zigzags and grecques. These vessels also must have been of large size. A single sherd also with painted decoration but of much thinner ware, and evidently a fragment of a small bowl, with decoration consisting of cross-hatching around the margin only, may be regarded as related to the thick, heavy ware in type. One other type is represented by a sherd of dark gray ware, very hard burned. In thickness it is similar to the smooth red ware, but the surface is decorated by parallel rows of thumb-nail impressions.

The character of the sherds would seem to indicate that the site was one belonging to Indians of the Guarani group of the Tupi. These Indians are known to have occupied the region in this immediate vicinity at the period of the earliest European contact, and sherds resembling the second and third types here described, have been found widely throughout this coastal region as well as over large areas of Uruguay and along the lower Paraná.

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PLATE 1.

PLATE 1.

Valle do Retiro near Petropolis.

View in the Serra do Mar near head of the Valle do Retiro back of Petropolis looking down the Valle do Retiro across the Valley of the Piabanha, a stream flowing north to join the Parahyba. Pedra d'Aço, the culminating peak of the radiating ranges, of which the mountains in the background form a part, attains an elevation of 2,230 metres (7,306 ft.) A region of deep dissection of schistose rocks intruded by bosses of granite and dikes of more basic rocks, the schists and granites probably of Pre-Devonian age as farther south in the Serra do Mar region. Page 7.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON

VAL.DO R TIRO, NEAR PETROPOLIS.

PLATE 1.

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PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

VAL.DO RITIRO, NEAR PETROPOLIS.

PLATE 2.

PLATE 2.

Granite Boulders due to Weathering.

View on the shore of Florianopolis Island, Santa Catharina; on shore of bay south of the city of Florianopolis. This type of surficial boulder, due to secular weathering of the granite, is common in the granitic regions along the slopes and at the base of the Serra do Mar, particularly at sea-level. The well-known boulders of the "Furnas das Agassiz" at Tijuca, which with other phenomena gave rise, at the time of the Thayer Expedition to Brazil, to the now abandoned hypothesis of the glacial origin of these detached blocks, belong in the same class of effects of secular weathering since Tertiary times. Page 113.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

WEATHERED BOULDERS, FLORIANOPOLIS.

PLATE 3

PLATE 3.

The campos of São Paulo, between Faxina and São Pedro de Itararé a few miles west of the former place on the Carboniferous sandstone terrane, showing the dissected peneplain of southwestern São Paulo, and mode of travelling by "trolley." Page 13.

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THE CAMPOS OF SÃO PAULO, WITH PARTY EN ROUTE.

PLATE 4.

PLATE 4.

Ruins of the old Spanish fort at Penco (ancient Concepcion) on the eastern shore of Concepcion Bay, destroyed in the earthquake and tsunami of May 24, 1751. View looking N. 56° E, mag., December 13, 1908. These walls are the sole standing remnant of the old town of Concepcion. Page 33.

PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

RUINS OF OLD FORT AT PENCO, CHILE.

PLATE 5.

PLATE 5.

Pleistocene glacial gravels at San Rosendo, Chile, on the north bank of the Rio Bio Bio just inside the Longitudinal Valley. December 24, 1908, looking N. mag., from the railroad tracks just east of the Station. Page 131.

PHOTO BY J. B. WOODWORTH.

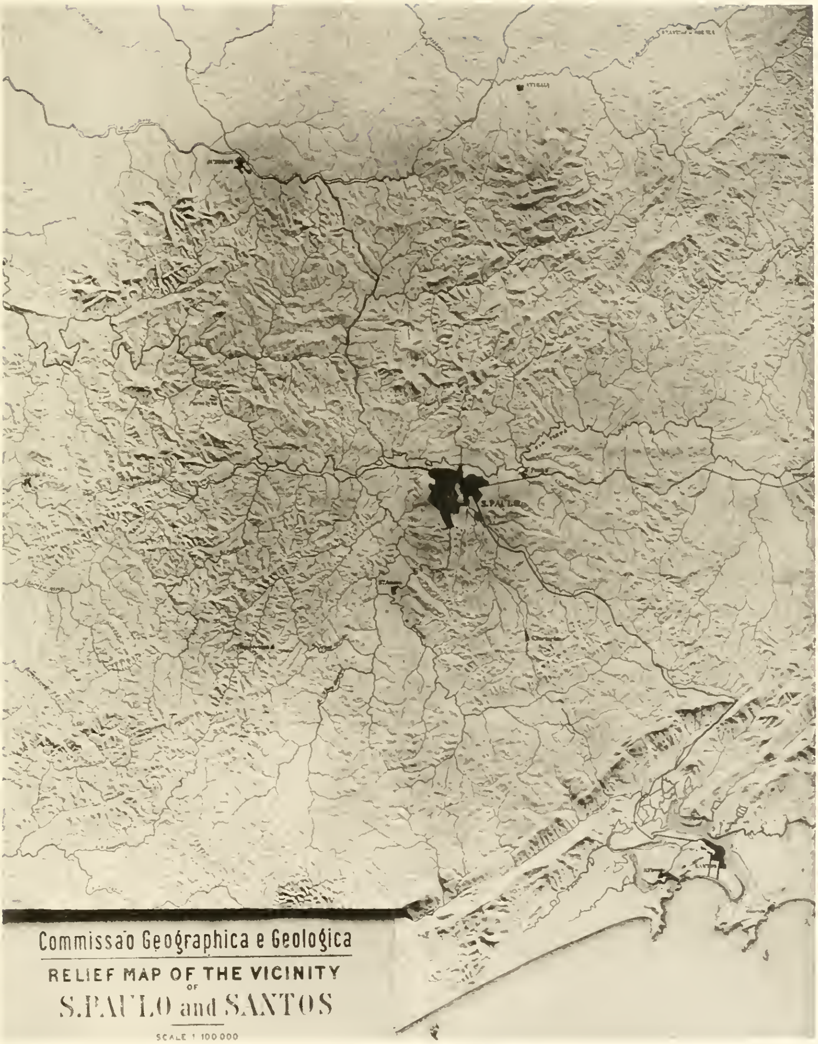
HELIOTYPE CO., BOSTON.

PLEISTOCENE GLACIAL GRAVELS AT SAN ROZENDO, CHILE.

PLATE 6.

PLATE 6.

Reproduction of a model of a portion of the state of São Paulo made by the Geographical and Geological Commission of São Paulo and based on the topographic surveys of Horatio E. Williams. The model brings out the detail of the erosion of the metamorphic and igneous Pre-Devonian belt forming the Atlantic slope of the highlands near Santos; the Serra do Japy southwest of Jundiahy. The roughened surface northeast of São Paulo may be regarded as the dying out of the Serra da Mantiqueira which range rises rapidly to the northeast of the area shown in the relief map. Except for the Tertiary basin in the smoothened area about São Paulo, the topography is developed on metamorphic and igneous rocks of the Pre-Devonian terrane. Page 99.



THE PLATEAU OF SOUTH BRAZIL IN EASTERN SÃO PAULO

PLATE 7.

PLATE 7.

The southern part of the city of Curityba, Paraná, looking west over the gently rolling surface of the peneplain developed on crystalline Pre-Devonian schists. The surface lies at an altitude of about 900 meters. Page 102.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO. BOSTON.

CURITYBA AND THE PENEPLAIN ON THE METEMORPHICS IN PARANÁ.

PLATE 8.

PLATE 8.

The Devonian area in Paraná looking northeastward, from the city of Ponta Grossa standing on Devonian shales, to the rising, rounded back of the westward dipping slope of the Devonian sandstone cuesta whose crest forms the sky-line of the view. Page 103.

PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

THE DEVONIAN AREA AND THE CREST OF THE SANDSTONE CUESTA SEEN FROM PONTA GROSSA.

PLATE 9.

PLATE 9.

The campos of São Paulo looking north from a point about eighteen kilometers west of Bury (Porto Apiahy), 128 miles inland and westward from the port of Santos, showing the smoothened surface of the peneplain of the Permian area, which is usually more rolling than shown in the view. Freight wagons and ant-hills in view. Treeless condition characteristic of large tracts. Page 102.

PHOTO. BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

THE CAMPOS OF SÃO PAULO, ON SANDSTONE TERRANE.

PLATE 10.

PLATE 10.

The Morro do Monge (Monk's Hill), near Lapa, Paraná; looking S. 46° E. mag., from eastern limits of village, August 14, 1908, showing cliffs of heavy bedded Permian sandstone overlying beds with waterworn gravels and outcropping layers carrying striated stones. Page 67.

PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

THE MORRO DO MONGE NEAR LAPA, PARANÁ.

PLATE 11.

PLATE 11.

View from Restinga Secca on the railroad between Ponta Grossa and Curityba looking S. W. over the Permian area in the valley of the Iguassú. August 4, 1908. Page 104.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

PERMIAN AREA IN THE VALLEY OF THE IGUASSÚ SEEN FROM RESTINGA SECCA, PARANÁ.

PLATE 12.

PLATE 12.

The gorge of the Iguassú at Serrinha, Paraná, west of Curityba. The Iguassú after leaving the baselevelled region about Curityba flows for several miles across the sandstones and boulder-beds at the base of the Permian system. The basal beds are regarded by some Brazilian geologists as possibly Devonian. Page 65.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

CAÑON OF THE IGUASSÚ AT SERRINHA, PARANÁ.

PLATE 13.

PLATE 13.

Pleistocene surficial gravels at Tamanduá, Paraná, in a railroad cut north of the Station, on the westward dip-slope of the Permian sandstone cuesta. These gravels occur on the interstream slopes here and there. Page 108.

PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

PLEISTOCENE GRAVELS AT TAMANDUÁ, PARANÁ.

PLATE 14.

PLATE 14.

Section in the red residual clays of the campos bordering the valley of the Iguassú at Lago, south of Ponta Grossa, Paraná. In outward respects similar to the *terra roxa*. Ant-hills shown on the surface. Page 112.

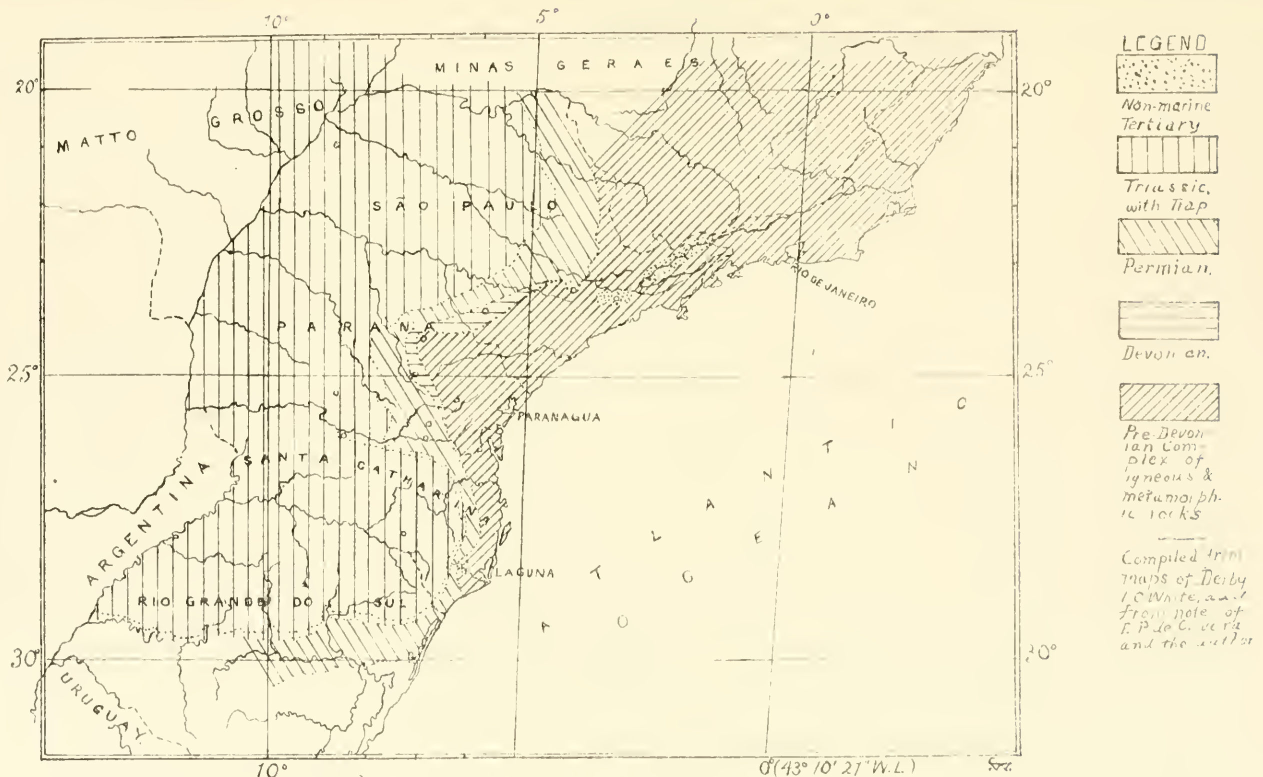
PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON

RED CLAYS AT LAGO, PARANÁ, VALLEY OF THE IGUASSÚ.

PLATE 15.

PLATE 15.

Sketch map of the geology of south Brazil, based upon surveys by Dr. Orville A. Derby, Dr. I. C. White, the publications of Dr. J. C. Branner, and upon field observations by Dr. Euzebio P. de Oliveira and the writer. The boundary of the trap sheet and consequently of the sedimentary area about Lages in Santa Catharina is drawn without any claim to approximation of its true position on the south, and the eastern limits of the effusive trap sheets in western São Paulo and northern Paraná are likewise indefinite. No attempt is made to delineate the numerous exposures of intrusive sheets giving rise to the *terra roxa* of São Paulo and northern Paraná. Page 41.



Sketch-map of the Geology of Southern Brazil.

PLATE 16.

PLATE 16.

The Serra Geral from Minas in the Tuberão Valley.

The dim wall in the background is the escarpment of erosion formed by the Triassic trap sheets and the underlying sandstones, below which comes the Permian shales. The foreground, looking up the Tuberão just east of the Lauro Müller railway station is on the Permian plant-bearing shales. The coal mines at Minas occur at a higher level to the left of the view. According to Dr. I. C. White this wall from the top down presents the following section:—

1. Eruptive rocks, mostly diabase, amygdaloidal and otherwise, 600 M.
2. Massive grey and red sandstones and conglomerates with intruded sheets and dikes of diabase. 200 M.

Red sandstones and shales, a massive red sandstone at the base resting with slight unconformity upon limestone, approximately 100 M. The rocks below are referred to in the accompanying text. Page 92.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO. BOSTON.

THE SERRA GERAL FROM MINAS IN THE TUBERÃO VALLEY.

PLATE 17.

PLATE 17.

Rio das Marombas in Santa Catharina.

View looking east across typical tributary of the Paraná in the trap plateau on the pack-train route between Corytibanos and Porto da União. Butia palms and araucarian pines, with smoke of forest fire on left. Photo by J. B. W., August 30, 1908. The road crosses the Marombas northwest of Corytibanos. The view is looking southward. The river flows toward the right, southwestward towards its junction with the Rio Canoas, a tributary of the Rio Uruguay. The ferry is referred to on page 27.

PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO. BOSTON.

THE RIO MAROMBAS IN THE TRAP PLATEAU OF SANTA CATHARINA.

PLATE 18.

PLATE 18.

Augite porphyrite dike with numerous inclusions of sandstone, shale, and fragments of vesicular lava, about six miles north of Lages on the road to Corytibanos, Santa Catharina.

The cutting edge of the palaeontological hammer points out a small block of red sandstone. The upper long hunting knife point rests on a fragment of included trap; the German army knife lower down points to a light colored sandstone. View taken in a roadside wash-out, August 28, 1908. Page 95.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

BASIC DIKE WITH INCLUSIONS NEAR LAGES, SANTA CATHARINA.

PLATE 19.

PLATE 19.

Map of route from Rio Negro to Lages and return to São Jõao and Porto da União da Victoria.

This map is based on a manuscript map in possession of the Serviço Geológico e Mineralogico do Brazil. The route was plotted from notes taken by Dr. Euzebio Paulo de Oliveira. Light tricornered points represent camps going southward, solid symbols those on the return journey. Dates are given, *e. g.* viii. 27–28, should be read "night of August 27th to morning of August 28th. See page 15.


PORTO DA UNIÃO
Rio Iguassú
RIO NEGRO
Rio Negro
Rio Timbó
SERRA DO ESPIGÃO
SERRA GERAL
Campos de Guarda Mór
Rio Corrientes
CURYTIBANOS
Rio das Cachoeiras
Rio Canoas
Rio das Caveiras
LAGES
Campos de Lages
Rio Pelotas
Ponta Grossa
20'
8° (51° 10' 21" W. L. Greenwich) 10'

MAP [illegible]

[illegible]

PLATE 20.

PLATE 20.

Boulder of Pre-Permian Conglomerate in Permian sandstones near Villa Rafford Station, Sao Paulo.

This boulder lies in the decomposed glacial sands of the railway cut between kilometer posts 199 and 200 west of the railway station. It is composed of quartzite pebbles unlike any portion of the Permo-Carboniferous or Devonian series known to me in this district. There is a specimen in the collection of the Museum at São Paulo, said by Dr. Pacheco to be identical with this rock, which has all the characters of a basal conglomerate of a marine series of Pre-Devonian age, possibly to be located in the metamorphosed sedimentary belt on the east of the area in which these fragments have been found. Page 57.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO. BOSTON

BOULDER OF CONGLOMERATE IN PERMIAN AT VILLA RAFFORD, SÃO PAULO.

PLATE 21.

PLATE 21.

Tillite bed and glaciated stones near Sengéns, Paraná.

This view was taken on the 16th of September, 1908, in the then relatively fresh railway cuttings between Sengéns and Itararé, between kilometer posts 234 and 235 on the south side of the Rio Jaguaricatu. The wall of rock in the background is a somewhat softened boulder-clay with scattered stones and small boulders, one of which is seen protruding to the right of the white square (block of field-labels). The loose stones in the foreground were picked up in the immediate vicinity on the floor of the excavation. The largest boulder is granite; the next but smaller on the left is a white sandstone, probably of the basal Devonian; the stone on the extreme right is a dark greenish rock not determined. To the left of the hammers is to be seen a well-striated reddish brown sandstone, probably a fragment of the disrupted glacial floor. Page 62.

PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

TILLITE BED AND GLACIATED STONES NEAR SENGÉNS, PARANÁ.

PLATE 22.

PLATE 22.

Block of fine white sandstone nine feet long in tillite bed near Sengéns, Paraná.

View taken September 16, 1908, in railway cut between kilometer posts 235 and 236 between Sengéns and Itararé, south side of track, showing a large block 9 ft. (or three meters) long of a fine-grained white siliceous sandstone, embedded in a typical glacial conglomerate or tillite. This bed lies a few feet above strata of the same lithological appearance as the erratic. Page 62.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

BLOCK NINE FT. LONG IN TILLITE AT SENGÉNS, PARANÁ.

PLATE 23.

PLATE 23.

Spheroidal separation in tillite near Rio Negro, Santa Catharina, south of the river of the same name.

View taken September 20, 1908, of a roadside cut, looking northwest, about half an hour's ride from Rio Negro on the road to São Bento, on the south side of the Rio Negro. This bed overlies the shales shown in Plate **24**. See small map page 68.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

SPHERICAL SEPARATION IN TILLITE NEAR RIO NEGRO, SANTA CATHARINA.

PLATE 24.

PLATE 24.

Ice-rafted boulder and stones in shales near Rio Negro, Santa Catharina. Same locality as Plate **23**. This shale underlies the earthy bed shown in Plate **23**, and contains near bottom of view a 1.5 inch band of the same material. Surface shows the herbaceous growth of the open lands between forested tracts. The boulder is a gneiss. Page 68.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

ICE-RAFTED BOULDERS AND STONES IN PERMIAN SHALES NEAR RIO NEGRO, SANTA CATHARINA.

PLATE 25.

PLATE 25.

Water-laid conglomerate at Orleans, Sta. Catharina. Page 73.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

WATER-LAID CONGLOMERATE AT ORLEANS, SANTA CATHARINA.

PLATE 26.

PLATE 26.

Permian shales resting on granite, with boulder, near Minas, Sta. Catharina. Page 74.

PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

PERMIAN SHALES RESTING ON GRANITE NEAR MINAS, SANTA CATHARINA.

PLATE 27.

PLATE 27.

Glaciated pebbles from tillite beds of Paraná. Page 76.

PEBBLES FROM TILLITE BEDS OF PARANÁ.

PLATE 28.

PLATE 28.

The coast chart of Valdivia River and Corral entrance, Chile. Page 122.

PORT OF VALDIVIA

PLATE 29.

PLATE 29.

Corral and the Cordillera Costal. Page 122.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

CORRAL AND THE COASTAL CORDILLERA, CHILE.

PLATE 30.

PLATE 30.

Rock-terrace around Manzera Island, Corral Harbor, Chile. Page 122.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

ROCK TERRACE AROUND MANZERA ISLAND, CORRAL HARBOR.

PLATE 31.

PLATE 31.

Rock-terrace on Valdivia River opposite Cutupal. Page 122.

PHOTO. BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

ROCK TERRACE IN VALDIVIA RIVER OPPOSITE CUTUPAI.

PLATE 32.

PLATE 32.

Drong of schist on fifty to sixty foot terrace near English Bay, south of Corral entrance, Chile. Page 123.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

DRONG OF SCHIST ON 50-60 FT. TERRACE NEAR ENGLISH BAY.

PLATE 33.

PLATE 33.

Sea-cave at upper marine limit near Palo Muerto Point, south of Corral entrance, Chile. Page 124.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

SEA-CAVE AT UPPER MARINE LIMIT NEAR PALO MUERTO POINT.

PLATE 34.

PLATE 34.

Coast chart of Concepcion Bay, Chile. Page 125.

CONCEPCION BAY, CHILE.

[illegible] CO., BOSTON

PLATE 35.

PLATE 35.

Talcahuano and the country south of Concepcion Bay. Page 126.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

TALCAHUANO AND THE COUNTRY SOUTH OF CONCEPCION BAY.

PLATE 36.

PLATE 36.

Tumbres Peninsula; looking west from deck of steamer at anchorage. The flattish sky-line is that of a roughened peneplain. Page 126.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO., BOSTON.

TUMBRES PENINSULA.

PLATE 37.

PLATE 37.

Modern Concepcion on the Rio Bio Bio. Chile. Page 125.

PHOTO BY J. B. WOODWORTH. HELIOTYPE CO. BOSTON.

MODERN CONCEPTION ON THE RIO BIO BIO.

The following Publications of the Museum of Comparative Zoölogy are in preparation: —

LOUIS CABOT. Immature State of the Odonata, Part IV.
E. L. MARK. Studies on Lepidosteus, continued.
" On Arachnactis.
A. AGASSIZ and C. O. WHITMAN. Pelagic Fishes. Part II., with 14 Plates.
H. L. CLARK. The "Albatross" Hawaiian Echini.
S. GARMAN. The Plagiostomes.

Reports on the Results of Dredging Operations in 1877, 1878, 1879, and 1880, in charge of ALEXANDER AGASSIZ, by the U. S. Coast Survey Steamer "Blake," as follows:—

A. MILNE EDWARDS and E. L. BOUVIER. The Crustacea of the "Blake."
A. E. VERRILL. The Alcyonaria of the "Blake."

Reports on the Results of the Expedition of 1891 of the U. S. Fish Commission Steamer "Albatross," Lieutenant Commander Z. L. TANNER, U. S. N., Commanding, in charge of ALEXANDER AGASSIZ, as follows:—

K. BRANDT. The Sagittae.
" The Thalassicolae.
O CARLGREN. The Actinarians.
W. R. COE. The Nemerteans.
REINHARD DOHRN. The Eyes of Deep-Sea Crustacea.
H. J. HANSEN. The Cirripeds.
" The Schizopods.
HAROLD HEATH. Solenogaster.
W. A. HERDMAN. The Ascidians.
S. J. HICKSON. The Antipathids.
E. L. MARK. Branchiocerianthus.
JOHN MURRAY. The Bottom Specimens.
P. SCHIEMENZ. The Pteropods and Heteropods.
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—— The Salpidae and Doliolidae.
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Reports on the Scientific Results of the Expedition to the Tropical Pacific, in charge of ALEXANDER AGASSIZ, on the U. S. Fish Commission Steamer "Albatross," from August, 1899, to March, 1900, Commander Jefferson F. Moser, U. S. N., Commanding, as follows:—

H. L. CLARK. The Holothurians.
—— The Volcanic Rocks.
—— The Coralliferous Limestones.
J. M. FLINT. The Foraminifera and Radiolaria.
S. HENSHAW. The Insects.
R. VON LENDENFELD. The Siliceous Sponges.
H. LUDWIG. The Starfishes and Ophiurans.
G. W. MÜLLER. The Ostracods.
MARY J. RATHBUN. The Crustacea Decapoda.
RICHARD RATHBUN. The Hydrocorallidae.
G. O. SARS. The Copepods.
L. STEJNEGER. The Reptiles.
C. H. TOWNSEND. The Mammals, Birds, and Fishes.
T. W. VAUGHAN. The Corals, Recent and Fossil.
—— The Annelids.

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OF THE

MUSEUM OF COMPARATIVE ZOÖLOGY

AT HARVARD COLLEGE.

There have been published of the BULLETIN Vols. I. to LII.; of the MEMOIRS, Vols. I. to XXIV., and also Vols. XXVI. to XXIX., XXXI. to XXXIV., XXXVII., XXXVIII., and XLI.

Vols. LIII. to LVII. of the BULLETIN, and Vols. XXV., XXX., XXXV., XXXVI., XXXIX., XL., XLII. to XLVIII. of the MEMOIRS, are now in course of publication.

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Reports on the Results of Dredging Operations from 1877 to 1880, in charge of Alexander Agassiz, by the U. S. Coast Survey Steamer "Blake," Lieut. Commander C. D. Sigsbee, U. S. N., and Commander J. R. Bartlett, U. S. N., Commanding.

Reports on the Results of the Expedition of 1891 of the U. S. Fish Commission Steamer "Albatross," Lieut. Commander Z. L. Tanner, U. S. N., Commanding, in charge of Alexander Agassiz.

Reports on the Scientific Results of the Expedition to the Tropical Pacific, in charge of Alexander Agassiz, on the U. S. Fish Commission Steamer "Albatross," from August, 1899, to March, 1900, Commander Jefferson F. Moser, U. S. N., Commanding.

Reports on the Scientific Results of the Expedition to the Eastern Tropical Pacific, in charge of Alexander Agassiz, on the U. S. Fish Commission Steamer "Albatross," from October, 1904, to April, 1905, Lieut. Commander L. M. Garrett, U. S. N., Commanding.

Contributions from the Zoölogical Laboratory, Professor E. L. Mark, Director.

Contributions from the Geological Laboratory.

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Bulletin of the Museum of Comparative Zoölogy

AT HARVARD COLLEGE.

Vol. LVI. No. 2.

GEOLOGICAL SERIES, Vol. X.

THE SQUANTUM TILLITE.

By Robert W. Sayles.

With Twelve Plates.

CAMBRIDGE, MASS., U. S. A.

PRINTED FOR THE MUSEUM.

January, 1914.

REPORTS ON THE SCIENTIFIC RESULTS OF THE EXPEDITION TO THE EASTERN TROPICAL PACIFIC, IN CHARGE OF ALEXANDER AGASSIZ, BY THE U. S. FISH COMMISSION STEAMER "ALBATROSS," FROM OCTOBER, 1904, TO MARCH, 1905, LIEUTENANT COMMANDER L. M. GARRETT, U. S. N., COMMANDING, PUBLISHED OR IN PREPARATION:—

A. AGASSIZ. V.[5] General Report on the Expedition.
A. AGASSIZ. I.[1] Three Letters to Geo. M. Bowers, U. S. Fish Com.
A. AGASSIZ and H. L. CLARK. The Echini.
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[1] Bull. M. C. Z., Vol. XLVI., No. 4, April, 1905, 22 pp.
[2] Bull. M. C. Z., Vol. XLVI., No. 6, July, 1905, 4 pp., 1 pl.
[3] Bull. M. C. Z , Vol. XLVI., No. 9, September, 1905, 5 pp., 1 pl.
[4] Bull. M. C. Z., Vol. XLVI., No. 13, January, 1906, 22 pp., 3 pls.
[5] Mem. M. C. Z., Vol. XXXIII., January, 1906, 90 pp., 96 pls.
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[16] Mem. M. C. Z., Vol. XXXVII., February, 1909, 243 pp., 48 pls.
[17] Mem. M. C. Z., Vol. XXXVIII., No. 1, June, 1909, 172 pp., 5 pls., 3 maps.
[18] Bull. M. C. Z., Vol. LII., No. 9, June, 1909, 26 pp., 8 pls.
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[21] Mem. M. C. Z., Vol. XLI., August, September, 1910, 323 pp., 56 pls.
[22] Bull. M. C. Z., Vol. LIV., No. 7, August, 1911, 38 pp.
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[26] Bull. M. C. Z., Vol. LIV., No. 12, April, 1912, 38 pp., 2 pls.
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THE SQUANTUM TILLITE.

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No. 2.— *The Squantum Tillite.*

By Robert W. Sayles.

Introduction.

For many years the origin of the Roxbury conglomerate has been a matter of debate. In 1869 Prof. N. S. Shaler stated his belief in the marine origin of this formation (Shaler, 1869, p. 172–177). Later on, in his lectures he considered the conglomerate to be of glacial origin. In some of his published statements the same idea may be found (Shaler *et al.*, 1899, p. 37–38, 57–59, 64–67). Prof. W. O. Crosby thought that the Roxbury conglomerate was of marine origin (Crosby, 1890, p. 10–17). Mr. W. W. Dodge believed in the glacial origin of the Roxbury conglomerate (Dodge, 1875, p. 408–409). Prof. J. B. Woodworth, although not publishing his views, has often expressed his opinion that the conglomerate was of glacial origin. Prof. George R. Mansfield did not indicate any decided view as to the origin of the Roxbury conglomerate, but in his conclusions (Mansfield, 1906, p. 256–257) favored strongly the glacial idea. In the last paragraph of this section of his paper he says: "The great quantity of large pebbles of relatively fresh granite and the abundance of felspathic material in the sandstones and in the matrices of the conglomerates suggest that much material was furnished to the streams of that time by glaciers of which no direct evidence now exists."

In view of the fact that tillite of Permian age has been found in every continent except North America, the discovery of what appears to be tillite in the Roxbury conglomerate is important. Glacial beds of Huronian age have already been found in Canada by Prof. A. P. Coleman, (Coleman, 1907) and Mr. J. A. Taff (1909), has found ice-borne boulders in mid-Carboniferous shales in Oklahoma.

On the 19th of December, 1909, I was gathering specimens of rock with Dr. Laurence La Forge, just south of Boston, for the Harvard Geological Museum. Dr. La Forge, who was at that time engaged in making a geological survey of the Boston region for the United States Geological Survey, had come upon a curious exposure of the Roxbury conglomerate at a locality in Hyde Park, across the street from the Becker Milling Machinery Company. The rock appeared to have all

the characters of glacial till, and I suggested that it was tillite. We visited another locality at the junction of Ware and Centre Streets in Roslindale where Dr. La Forge had found the same characters in the rock, and this time were accompanied by Profs. W. M. Davis and J. B. Woodworth. All agreed that this rock looked very much like tillite. We visited the Hyde Park locality, and Professors Davis and Woodworth were strongly of the opinion that the rock was tillite, though the proof was still wanting.

Criteria for the determination of till or tillite.

As all till varies a great deal in its character in different localities and in the neighboring exposures of the same locality, it is difficult or impossible to give a short definition of it. Strictly speaking, the only characteristic common to all tills and tillites is, that they are made up of a miscellaneous, unsorted, unstratified mass of rock-débris laid down by a glacier. As a rule till is composed of rock-flour or clay and rock fragments, and in this mixture the matrix of rock-flour or clay is a large part of the mass. The matrix, though more often of clay, is sometimes sand of varying texture.

Usually a majority of the stones in till are angular or bluntly angular (subangular), with several facets. Many have an oblong shape with one or more flat sides or soles, smoothed or polished. Some of the stones in till are rounded, water-worn pebbles, but these are usually in the minority. Where a glacier has pushed over gravel-beds, many water-worn pebbles become included in the till without being fractured or scratched. In southern Rhode Island the writer has seen till made up almost entirely of rounded pebbles. In this case the glacier retreated; the water from the melting ice deposited materials at its front; the glacier then advanced over these deposits, which had in the meantime become water-worn, making of them a mass which can receive no other name than till. Here pebbles more than equalled the sandy matrix in amount.

Scratches or striae on the stones in the till are considered of prime importance, in the proof of the glacial origin of a miscellaneous, unsorted, and unstratified mass like till. There is no doubt that striae are most important, but they are not always conclusive proof of glacial origin where present, and on the other hand the absence of them is not conclusive proof of the non-glacial origin of any till-like deposit. There are several mechanical agencies in nature capable of producing striae besides glaciers; and over some areas in many parts

of the earth, the till contains no striated pebbles. It is not always possible to say why striae are wanting in some regions. Where the pebbles are mostly of some very hard rock like quartzite, the striae, on account of the hardness of the substance, may be nearly absent. I mention this absence of striae because so many geologists, on this account, doubt the glacial origin of certain tillites.

Striated stones are frequently blunted at one or both ends, or turned to a point at one end and blunted at the other end. They are also in many cases bevelled on one or more sides. If a stone is too hard to take the striations the blunting or bevelling effects may still be present.

In addition to the angular, subangular, oblong, facetted, bevelled, striated pebbles, there is another mark of glaciation on stones in the drift which has not received sufficient attention from geologists. This characteristic, so often mentioned to me by Prof. J. B. Woodworth, is of as much importance in determining the glacial origin of till or tillite as the striated stones. I have reference to the concave fractures which appear on many glaciated stones. These are as positive a mark of glaciation as striae, and fractures of this nature can be found as frequently as striae or even more so. Such fractures must be produced by crushing under a tremendous pressure of ice, in which case the fractured pebble would probably lie between another rock fragment and a rock-floor, or where there is no rock-floor, between two other rock fragments (Woodworth, 1912, p. 76–77).

As a rock-floor or striated pavement has been found beneath several tillites, some geologists have not been convinced of the glacial origin of tillites which have no grooved rock-floor or striated pavements. The principal objection to Professor Coleman's glacial deposit in the Huronian was just this point; but no rock-floor in the case of some accepted tillites has been found (Coleman, 1908, p. 354).

Glacial deposits are made up of a great variety of rocks. In till or tillite may be found rock fragments which have been transported many miles from the parent ledge. This great variety is not found in gravels formed under cliffs where there has been no glacial action, nor in local river-gravels where the stream has had a short course and acted on the local rocks.

The crushed fragments of the till or tillite show fresh rock and not weathered materials.

In many deposits of till and tillite pieces of the local, underlying, at the time unconsolidated beds over which the glacier has passed may be found, together with those derived from a distance.

According to Stone (1899, p. 29–30), the lower part of a bed of till

has usually a finer matrix than the upper part, and in the lower part the striated pebbles are much more abundant.

In beds of till or tillite intercalated layers or beds of gravel, sand, or clay may be found. Strictly speaking till is unstratified, but Sir Archibald Geikie (1903, p. 1310) writes as follows: — "In general, boulder clay is unstratified, its materials being irregularly and tumultuously heaped together. But rude traces of bedding may not infrequently be detected, while in some cases, especially in the higher clays, distinct stratification or intercalated seams of sand or gravel may be observed." Prof. James Geikie (1895, p. 14) describes these intercalations as follows: —"Another characteristic of till is the not infrequent occurrence of included nests and lenticular layers, and occasionally thick beds of gravel, grit, sand, and brick-clay. Sometimes these lie in approximately horizontal or gently inclined positions, but usually they are more or less disturbed, and often curiously curled up and contorted, so as to present the appearance of having been rolled over upon themselves along with the clay in which they are inclosed."

Considering all the different characteristics of till and tillite, it is necessary to conclude that the proof of till or tillite lies, not in the finding of any one or two glacial characters which a given deposit may possess, but in the sum total of the characters found. In the different exposures of a bed which has the appearance of till or tillite, there should be found a majority of the characteristics of till. The list of criteria given above contains the most important characters, and the following resumé is given as an aid in forming an opinion of the glacial characters found in the tillite described in this paper.

A. An unstratified mass of miscellaneous, and unsorted rock materials.
B. The matrix usually of rock-flour or clay, but sometimes of sand.
C. The included rock fragments usually angular or subangular, with several facets.
D. Some rounded, water-worn pebbles or boulders.
E. Striated pebbles, rock fragments, and boulders.
F. Stones blunted at one or both ends, or rather pointed at one end and blunted at the other end.
G. Fragments bevelled on one or more sides, the sides usually not parallel but making an angle with each other.
H. Concave fractures.
I. Till or tillite resting on a grooved or striated rock-floor or striated pavement.
J. Great variety in kinds of materials.

K. The lower part of the till usually has a finer matrix and more striated pebbles than the upper part.
L. The materials in till showing that when deposited there was no evidence of weathering or decomposition.
M. Materials in till usually composed of more local than foreign rocks.
N. Near the top of till, intercalated stratified beds may be found.
O. Included "nests" and layers often contorted.

Description of localities.

In descriptions of conglomerates the words "pebbles" and "boulders" are used, as a rule, very indefinitely. In this paper I propose to use the word *pebble* for sediment from $\frac{1}{8}$ of an inch up to 5 inches; the word *boulderet* for rock fragments from about 6 inches up to 1 foot in diameter; the word *boulder* for rock fragments over 1 foot in diameter.

Locality 1. Hyde Park. At Hyde Park the sandstone and conglomerate beds just under the tillite, strike N 30° E, and dip 70° S. About 100 feet of the tillite is exposed. The matrix of the tillite is very fine, originally of clay. So far as I have observed them the pebbles, boulderets, and boulders are of granite, felsite, and quartzite, but other varieties may be found later. The shapes of the rock fragments indicate glaciation; angular and subangular for the most part, but here and there rounded. Dr. La Forge found a well-striated pebble embedded in the matrix, in the presence of Dr. Ellsworth Huntington and the writer on July 11th, 1910. This pebble is shown in Plate 2. I have since found two others from this outcrop. There is a large boulder of granite in the matrix within a few feet of the place where Dr. La Forge found his striated pebble, beyond the fence back of the Becker Milling Machinery Company's storehouse. This boulder measures somewhat over three feet in diameter, and is angular. This spot is very near the bottom of the tillite, where it would be most natural to find striated and well-glaciated pebbles. There are no intercalated beds visible in the tillite of this outcrop, and absolutely no stratification of any kind. No fragments of slate have been found, and this is an important fact to be dwelt upon later. I have found no melaphyre fragments or pebbles. Shearing is intense. See Plate 1.

Below the tillite there are some transition-beds of conglomerate and sandstone about 100 feet thick.

Criteria found (see page 144):—A, B, C, D, E, F, G, H, J, K, L, M.

Locality 2. Milton Upper Mills. At Milton Upper Mills, about one tenth of a mile east of Blue Hill Avenue on Eliot Street, 200 feet from the road on the left, in woods, there may be seen an outcrop which has many of the characteristics of tillite. The strike and dip were not obtainable. There are about fifty feet exposed. The matrix is gritty argillite. Pebbles are angular, subangular, and rounded. There is no stratification seen.

Criteria found.— A, B, C, D, F, J, L.

Locality 3. Roslindale. In Roslindale, south of the Arnold Arboretum, fifty feet east of the junction of Weld and Centre Streets, there is an old quarry in the tillite. No strike or dip can be found near the tillite. The thickness is problematical on account of the heavy covering of Pleistocene drift. About 200 feet are exposed in a north-south direction. The matrix is argillaceous as at Hyde Park. Boulders up to two feet are common. The pebbles are angular, subangular, and rounded. Blunted pebbles with concave fractures are common, and also bevelled pebbles. I believe this outcrop to be near the bottom of the tillite as at Hyde Park. I have found one pebble with very faint striae, well bevelled and blunted. There are no signs of stratification in this bed. Shearing has been intense.

Criteria found: — A, B, C, D, F, G, H, J, K, L, M.

Locality 4. Roslindale. Another exposure in Roslindale may be seen south of the above. Strike and dip not observed. About twenty feet only are exposed, in a north-south direction. The matrix here is arenaceous. Pebbles and boulders up to a foot in diameter may be found, of angular, subangular, and rounded shapes. No new kinds of rocks have appeared. I have found no shale or slate fragments. A striated quartzite pebble was obtained having three striae. Two of these are parallel, and a third makes an angle of 11° with the others. This pebble is angular with blunted ends and a concave fracture. Cleavage well developed at this locality.

Criteria found: — A, B, C, D, E, F, J, L.

Locality 5. South of Forest Hills Cemetery. About 600 yards southwest of the Forest Hills Cemetery locality, and 100 yards east of the trolley line, there is a fair exposure of the tillite. The strike and dip were not obtainable. The thickness is also unknown. On the strike of the Cemetery exposure given below, there are 150 feet visible. The matrix is gritty argillite. The pebbles, boulderets, and boulders are angular, subangular, and rounded, consisting of granite, felsite, quartzite, melaphyre. I have not seen any shale or slate fragments. No striated pebbles have yet been found. There are no

signs of stratification, and no visible contacts with underlying or overlying beds. Cleavage is well developed.

Criteria found: — A, B, C, D, J, L.

Locality 6. Forest Hills Cemetery. In the Forest Hills Cemetery there is a small outcrop of tillite. This rock may be found about 100 feet from the fence north of Walkhill St., opposite the crematorium. Here the strike at the contact with slate is N 72° E, and the dip 70° S. It is not possible to obtain the thickness. About twenty-five feet are exposed. Measuring toward the west there is a distance of 335 feet to an outcrop of sandstone, and the latter is exposed twenty-five feet. The sandstone is in contact with the main body of the Roxbury conglomerate. The characters of the tillite are much like those at Squantum Head, to be described later. Thin layers of shale or slate may be seen in the tillite a few feet from the slate contact. The matrix is arenaceous; the pebbles of all shapes, angular, subangular, and rounded. The materials of the pebbles are the same as at all the exposures with no additional varieties yet found. The largest fragment found was about one foot in diameter. Several shale or slate fragments were found mixed with the pebbles. There are no transition-beds to the Cambridge slate, and in this the deposit resembles that at Squantum Head. Cleavage is well developed. No striated pebbles were found.

Criteria found: — A, B, C, D, J, L, M, O.

Locality 7. New Calgary Cemetery. At New Calgary Cemetery, one fifth of a mile south of Walkhill St., close to the fence on the east, a small outcrop of what appears to be tillite may be seen. The strike of the beds just south is E 6° S, and the dip 76° W. The thickness here is not obtainable. The matrix is a gritty argillite. No stratification is visible. The pebbles have angular, subangular, and rounded shapes. The position of this bed is right for tillite, the transition-beds coming to the south, and south of these the main body of the Roxbury conglomerate, while to the north comes thick slate. Very little more can be said of this outcrop except that the pebbles so far as visible are of granite, and felsite.

Criteria found: — A, B, C, D, J.

Locality 8. Morton Street. About fifty feet south of Canterbury Street on Morton Street there is an outcrop which resembles very closely the tillite at the junction of Blue Hill Avenue and Harvard Street. No strike or dip have been obtainable. The matrix is arenaceous. Pebbles are angular, subangular, and rounded. Cleavage noted.

Criteria found: — A, B, C, D, F, H, J, L, M.

Locality 9. Franklin Field. At the junction of Blue Hill Avenue and Harvard Street there is an outcrop of tillite. No strike or dip are available. The breadth of the outcrop is about 100 feet. The matrix is a sandy slate. The included rock fragments are angular, subangular, and rounded. One striated pebble has been found. This pebble is shown in Plate 10. Blunted and bevelled stones are common. Several concave fractures have been found. The rock fragments are composed of granite, felsite, and quartzite. I have not found melaphyre, and there are no slate masses. There are no intercalated layers. The transition-bed or beds to the Roxbury formation are conglomerate, and not slate or sandstone as in localities farther south and southeast. Shearing was as intense at this locality as at any other.

Criteria found: — A, B, C, D, E, F, G, H, J, K, L.

Locality 10. Atlantic. About one half of a mile southwest of the aviation field at Atlantic, on a wooded knoll, a very important exposure of the tillite may be seen. The series of beds here commences well down in the Roxbury conglomerate proper, and in almost continuous outcrops ends near the middle of the tillite. This is the best exposure of the beds underlying the tillite, with the tillite bed itself well exposed. Commencing at the most northern extremity of the knoll the Roxbury has a strike of N 42° E, with a dip of 45° S. The transition-beds below the tillite have a strike of N 48° E, and a dip of 70° S. Thicknesses of beds in this section are as follows: — Roxbury conglomerate 520 feet; a sandstone bed twenty-five feet; conglomerate, sandstone, and slate 120 feet; contorted slate and sandstone forty-seven feet; conglomerate and sandstone 123 feet; tillite 298 feet. This gives a total for the section of 1,133 feet. In correcting the thickness of the Roxbury conglomerate an average dip of 57° was used, the dip at the bottom being 45° and at the contact with the first bed of sandstone 70°.

At this point it is necessary to describe some of the beds underlying the tillite, for the reason that two of these beds resemble a bed in Brighton. About fifty feet above the main body of the Roxbury formation, and just above a sandstone layer about 3 feet thick, there appears a bed of conglomerate with thin layers of slate and fragments of slate. These fragments are very irregular in shape and vary in size, although most of them are not over six inches in diameter. It is evident that this deposit is water laid, and that the fragments have been washed along with the pebbles. In view of the fact that much larger fragments of slate are found in the tillite at Squantum and

Atlantic, and that the same kind of argillaceous masses are found in the tillite of Australia (Wilkinson, p. 194) and other places, and in Pleistocene till, it is necessary to suppose — unless some better agency can be advanced — that moving ice tore up all these shale or slate fragments. A moving ice-sheet would tear up a clay-bed; part of the torn up mass would be over-ridden and dragged up into the till, and some of it would be seized by the glacial torrents and carried forward and deposited somewhere in front of the ice. It seems perfectly possible that this latter method explains these lumps deposited with the conglomerate. A large fragment would be rolled over along the bottom more easily than a rock of corresponding size, on account of the lower specific gravity of clay and lessened liability to wedging on account of ready marcellation when moved against an obstacle. In this way a large fragment might be moved for some distance and when finally brought to rest would be much reduced in size.[1] As for the fragments at Atlantic, the ice-front could not have been very far away, and a retreat must have followed, for above this horizon a slate bed is found. Another advance is indicated by another conglomerate bed with slate fragments and tillite. Above these beds come about 25 feet of sandstone with fine conglomeratic layers, and some shale or slate fragments, and in contact with this the main body of the tillite. Knowing that moving ice does disrupt clay-beds, and the proximity of the tillite to these shale or slate fragment horizons, this association makes it very probable that ice was the agency responsible for the fragments. I am well aware that such fragments may also be due to the undermining of clay-beds by streams, and the falling in of clay fragments so undermined, but the evidence in these cases under consideration points to ice-action.

The tillite has a very ragged contact with this underlying sandstone, as if the surface of that deposit had been disrupted by violent movement such as that of ice. In places the tillite appears to have been pushed down into the sandstone. The lower part has a fine argillaceous matrix with here and there coarse patches. About ten feet from the bottom the matrix is uniformly fine. Farther up in this main tillite bed the matrix becomes coarser and at the point highest up resembles very closely the tillite at Squantum Head.

[1] By experiment I have found that frozen clay disintegrates as soon as it comes in contact with water. The temperature of the water used was about 32° F. Plastic clay in an unfrozen condition does not disintegrate with anything like the same rapidity. It is inferred from this that the clay fragments under discussion were not frozen.

The included fragments at the bottom are composed of granite, melaphyre, felsite, quartzite, and very large masses of slate. The largest of the last measures at least six feet long by four feet wide. These slate fragments become scarcer upward, and almost disappear. As this exposure has been found very recently, no striated pebbles have as yet been discovered. The boulders, boulderets, and pebbles observed are angular and subangular for the most part, with rounded water-worn individuals here and there. Pink granite predominates over all other varieties of rock. This is true both for the underlying Roxbury conglomerate and the tillite. Melaphyre is well represented and in large fragments, as at the Squantum exposures. An intercalated bed of conglomerate about two feet thick in the tillite, about 150 feet above the sandstone is the equivalent of a similar but thicker bed at Squantum Head. Such beds in tillite are very variable. Shearing has given a well-developed cleavage with sharp dips in a northerly direction.

Criteria found: — A, B, C, D, F, H, J, K, L, M.

Locality 11. Atlantic-Squantum Knoll. To the north of Atlantic on the road to Squantum and about three fourths of a mile southeast of the aviation field there is a little wooded knoll where tillite is exposed. It is not possible to be sure of strike or dip. Some intercalated beds occur on the shore, but they appear to be in blocks which have been moved by Pleistocene ice-action. About 100 feet of the tillite bed is exposed in separate outcrops. The matrix at this exposure is very fine, suggesting the lower part of the tillite. The included pebbles, boulderets, and boulders are of granite, melaphyre, felsite, and quartzite. The shapes of the fragments are as usual, angular and subangular, with a very few water-worn pebbles. As this exposure has been discovered very recently no search for striated pebbles or other marks of glaciation has been made. A block of melaphyre was found in the southeastern extremity of the outcrop showing a very angular outline. This block measures four feet long and one foot wide. Cleavage is well marked.

Criteria found: — A, B, C, D, J, K, L, M.

Dr. F. H. Lahee, of the Massachusetts Institute of Technology, has examined a specimen of tillite from this locality and writes me (14 February, 1913) as follows: —

"The specimen of tillite, from which I had the two thin sections made, was obtained on the eastern coast of a small hill at the head of Quincy Bay, three quarters of a mile southeast of the aviation field (Locality 11).

"The exposures at this place are large blocks which show occasional well marked, laminated strata of a fraction of an inch to two feet in thickness. Since these beds all dip vertically and strike in the same direction, I believe that they are practically *in situ*. Alternating with these strata are layers that absolutely lack any evidence of water sorting and water deposition.

"The sorted layers, sometimes of uniform width for many feet, consist of mudstone and sandstone. In the thickness of the entire cliff section they may represent 15 or 20 percent. The unsorted layers contain angular and irregularly shaped fragments of pinkish granite (the species so common in the Roxbury conglomerate), gray quartzite, greenish felsite, and dark green, chloritized melaphyre. There are some rounded pebbles. These fragments and pebbles are very variable in size. They range from grains of quartz and feldspar $\frac{1}{16}$ to $\frac{3}{16}$ of an inch in diameter to large boulders, the largest seen being four feet long. They are contained in a compact, greenish gray paste or matrix which comprises 50 to 75 percent of the bulk of the rock. Having no parallel structure of any sort — bedding or schistosity — the paste breaks with an uneven fracture. Although the term 'tillite' is applicable to the whole section, I use it here with reference only to the unstratified, unsorted portions. My thin sections were cut from a hand specimen of this tillite.

"When examined with the microscope, the finer part of the rock is found to be composed of minute grains of quartz and feldspar, very small laths of sericite, and a highly refracting, granular substance, uniformly distributed, which is probably epidote. The quartz and feldspar are so fine that little can be distinguished. The sericite laths show a tendency to parallel orientation, thus indicating some shearing in the rock, but not enough to produce a visible schistosity in the hand specimen. The laths are small and of nearly uniform dimensions. The paste may be said to consist of particles having the same size as these laths, or smaller. This mica constitutes between 20 % and 25 % of the matrix.

"In the paste are scattered grains of quartz and feldspar and small fragments of granite, quartzite, and melaphyre, as seen in the hand specimen. These grains and fragments are usually angular. The larger quartz particles exhibit slight wavy extinction and some cracking, and also fine peripheral granulation accompanied by the marginal insertion of sericite laths, characteristic of the early stages of dynamic metamorphism. Of the feldspar grains, examples of orthoclase, microcline, microperthite, and plagioclase (albite to oligoclase) were de-

termined. While most of these are considerably altered, either to sericite or to calcite, as the case may be, a few are remarkably clear and fresh.

"Now, as regards the origin of this tillite, there are two agents which have been ascribed to its formation,— vulcanism and ice. If this were a product of extrusive action, it would be called a tuff or an agglomerate, and in either case it should reveal signs of a former glassy nature of all or part of its components. To my mind, there is no suggestion of such an original structure. The rock does not at all resemble the tuffs and agglomerates found elsewhere in the Boston basin. On the other hand, if this were a typical till in a consolidated state, its finer parts should be composed largely of rock-flour; kaolin should not be an abundant constituent. Unfortunately the finer portion of the feldspar elements has gone to form sericite and calcite, and the original source of these secondary minerals is therefore not determinable; but the considerable amount of larger feldspar grains, many of them very little altered, suggests that kaolin was not abundant originally.

"In conclusion, then, I may say that the megascopic and microscopic study of this rock lead me to believe that ice was the most important factor in its deposition; but that water, too — standing or gently moving — was concerned in its origin. I could find no evidence of contemporaneous erosion throughout this section. Both upward and downward, stratigraphically, in the section, the tillite beds grade into the water-laid strata. Apparently the ice was either floating or had its weight much reduced by partial flotation."

In the above letter Dr. Lahee suggests possible flotation for the ice. I have not found any evidence that such was the case. In view of the large fragments of slate in the tillite, and the disrupted beds found at Squantum Southeast, not to mention the immense block of sandstone, fifteen feet in diameter, which is evidently part of a disrupted bed, I cannot agree with Dr. Lahee on the flotation idea. Again the first beds encountered at the top of the tillite are conglomerate of coarse texture, sandstone layers, then sandstone and slate, and last slate without sandstone. These beds would indicate that the water in front of the ice was at first shallow, and the slate would indicate that subsidence was in progress as the ice retreated. This transition may be seen to best advantage at the most southerly part of the Squantum Southeast exposure where the slate appears on the shore.

Locality 12. Squantum Southeast. At the end of the road running

farthest east on the peninsula of Squantum there are found many exposures of the tillite, and these different exposures range from near the bottom to the very top of the tillite, with transition-beds to the overlying slate. The strike of the slate here is N 63° E, and the dip 68° S. The thickness of the tillite is probably about 600 feet. The matrix near the bottom is argillaceous, while higher up and at the top it is a gritty argillite, and in one place is arenaceous. Boulders of many kinds may be found, but the largest and most numerous are of granite. The pebbles are angular, subangular, and rounded, and many have blunt ends and concave fractures. Prof. J. B. Woodworth

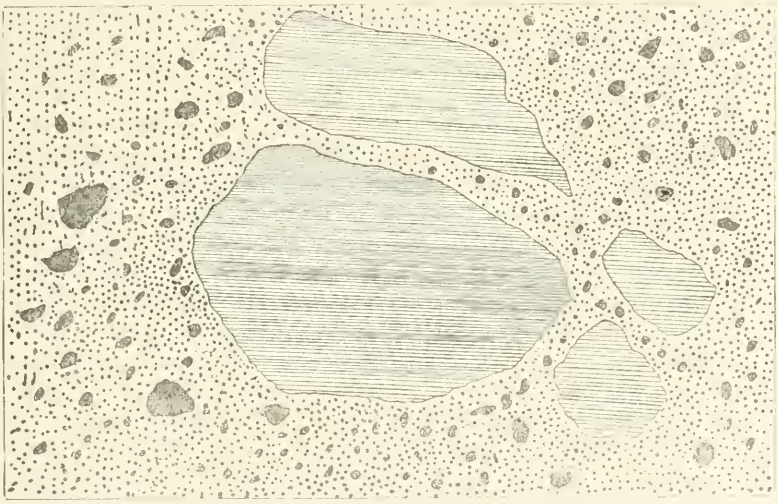

FIG. 1.— Disrupted sandstone in tillite: Squantum Southeast.

found a striated pebble at this locality. The striae are very faint, but with the aid of a pocket-lens appear perfectly characteristic.

As stated above, the tillite here has a probable thickness of about 600 feet. There is no good evidence that the bed is doubled by folding and from the most northerly exposure to the upper transition-beds the thickness is about as given. The lower contact with transition-beds is probably hidden beneath drift and beach-shingle. I believe that these lower transition-beds and a part of the Roxbury conglomerate underlie the tillite here and have not been faulted out. At the most northerly exposure and hence the lowest part of the tillite there

is found a large mass of sandstone about 15 feet in diameter, the upper part of which is stratified with layers of slate alternating with sandstone. It appears to have been a part of an underlying bed which had been disrupted and dragged laterally upward into the till. The entire mass is surrounded with tillite. This is by far the largest block yet discovered in the tillite. In view of the fact that a bed of sandstone underlies the tillite at Atlantic, it is inferred that this sandstone mass is a part of a similar bed disrupted and included in the tillite. That the lower transition-beds and the Roxbury conglomerate are present, but hidden from view in this locality is also inferred from the large amount of fragments of the conglomerate found in the drift on Squantum just where they should be found. The stone-walls are made up chiefly of this variety of rock. The sizes of the pebbles in the Roxbury drift fragments average the same as in the Roxbury at Atlantic; lithological characters are the same. The texture of the Roxbury conglomerate in different localities is extremely variable, and hence to find the same texture in these fragments as at Atlantic, on nearly the same strike and only a short distance away, would indicate that they were not transported far but came from this vicinity. The great preponderance of these Roxbury fragments over other kinds of rock would also indicate a local origin. It is from this evidence that I have felt justified in believing that the tillite here has not been doubled, but is a bed shown in its actual thickness.

Near the very top of the tillite there is a multitude of slate fragments, which had their cleavage developed after inclusion in the tillite. They have very irregular shapes, none of them being water worn, and many of them bent and twisted as if they had been in a plastic condition when the ice moved over the surface. It is evident that here the ice plowed over a clay-bed, breaking it up and dragging the clay fragments, thus disrupted, upward into the till. Some of these fragments are large, one measuring four feet long by two feet wide in the other dimension. Most of them are about a foot long. Shearing has changed the original shapes in some cases. It is clear, however, that the bending, twisting, and tearing observed in these cases has not been brought about by shearing. See Plate 8.

Dr. Ellsworth Huntington, who was with Dr. La Forge and myself on our first visit to this locality, found a very remarkable case of deformation in a slate bed. The bed in question is about three feet thick. A part of this bed has been turned up so that it makes an angle of about 90° with the original bedding for several feet, and about ten feet farther on the bedding again assumes its original position. There are two cases of this sort here not far apart.

In the tillite of New South Wales, Australia, there is a case very similar to those just described. The exposure was found by Mr. C. S. Wilkinson in 1879 in Permian, or Permo-Carboniferous tillite. It bears so closely on our problem here that it will be well to quote Wilkinson in part. He says: — "In the section exposed in the quarries at Fort Macquaire, Woolloomooloo, Flagstaff Hill, and other places, may be seen angular boulders of the shale of all sizes up to 20 feet in diameter, embedded in the sandstone in a most confused manner, some of them standing on end as regards stratification and others inclined at all angles. These angular boulders occur nearly always immediately above the shale beds, and are mixed with very rounded pebbles of quartz: they are sometimes slightly curved as if they had been bent whilst in a semi-plastic condition, and the shale beds occasionally terminate abruptly, as though broken off. Had the boulders of soft shale been deposited in their present position by running water alone, their form would have been rounded instead of angular. It would appear that the shale beds must have been partly disturbed by some such agency as moving ice, the displaced fragments of shale becoming commingled with the sand and rolled pebbles carried along by the currents." (C. S. Wilkinson, p. 194).

Where the slate fragments appear near the transition-beds the proportion of pebbles to matrix is large, suggesting thin ice acting for a short time. There are some sandstone beds intercalated in the tillite which have a strike differing by 8°–10° from the strike of the main body of the slate just above. According to James Geikie (1895, p. 24), this is characteristic of beds intercalated in till. These beds must have dipped to the west when deposited.

Cleavage is well developed throughout these outcrops. See Plate **9**.

Criteria found: — A, B, C, D, E, F, H, J, K, L, M, N, O.

Locality 13. Squantum Head. At Squantum Head about three fourths of a mile north of the exposure just described, there is a massive outcrop of tillite. Strike on the north at contact with the slate N 48° E, dip 25° S. These strikes and dips were taken west of a north and south fault line to be described later. The thickness is probably 600 feet. The matrix is arenaceous and argillaceous. Boulders, boulderets, and pebbles are of all shapes and sizes up to three and one half feet in diameter. The proportion of rounded pebbles is larger than at the other Squantum exposure, although angular ones are very common, and the latter show the usual shapes due to glaciation. Dr. Arthur Keith, in the presence of Dr. La Forge and the writer, found one pebble which he considered at the time to be ice worn, and I found a pebble bearing several glacial striae (Plate **10**). The pebbles are of

the usual kind found in the Roxbury formation: — granite, felsite, melaphyre, sandstone, quartzite, with some shale or slate fragments. The slate fragments found so abundantly in the exposure at Squantum farther south, and at Atlantic, are fewer here. A few may be seen near the contact with the slate. Near the middle of the tillite on the top of the hill there is an intercalated bed of water-laid gravel averaging about twenty feet thick. This bed may be seen again at the point of the Head on the north side. There is a north-south fault between the two exposures. On the glacial hypothesis it is apparent that the ice retreated and advanced again. On the shore to the north of a quarry which is on the top of the hill, may be seen a bed of sandstone about twenty feet thick and perhaps fifty feet from the bottom of the tillite at its contact with the lower slate. As this sandstone comes between two beds of tillite, it indicates another retreat and advance of the ice.

The fault mentioned above, cuts the tillite on a line near the front of the barn at the end of the road, and may be seen at the place on the shore where slate is encountered south of the dwelling house. Proceeding in a straight line from this point past the barn, the fault may be located on the north shore.

Dr. F. H. Lahee has observed plications in the slate south of the tillite bed which deserve notice here. The plications occur in layers of slate, and above and below such plicated layers the slate bedding has not been disturbed. The upper parts of the folds have been cut off, showing that the folding went on during the deposition. Dr. Lahee suggests that floating ice became grounded and compressed the layers, and later on when the same ice or other ice floated over these layers, the tops were cut off. Prof. James Geikie (1895, p. 271–274) has noted like plications in clay beds overlying the till at Portobello, Scotland, and he suggested grounding ice-rafts, as Lahee did, for the plicating agency. I have noted the same kind of folding in slate at Crow Point, Hingham, and at the Chestnut Hill fault locality, on Beacon Street west of Hammond Street, Chestnut Hill, but have not seen evidence of the cutting off of the folds at these localities. At the Atlantic exposure also folds in slate may be seen, with arches cut off as at Squantum Head. It is not impossible that the tops of these folds were removed by a swifter flow of water, as evinced at Atlantic by ripple-mark of fine sandstone above the folds. The same kind of folds, but not cut off, may be found in Pleistocene clays in many places in this country. Near Hanover, N. H., I have found many folds of this description. In view of the fact that the layers

above and below the folds have not been deformed, it is difficult to see how the folds could have been formed by simple gravity, especially when it is noted that the folding and deposition were nearly contemporaneous.

There is some difference of opinion among geologists who have visited Squantum Head as to whether the tillite bed is doubled by folding and part of the exposure inverted. Dr. La Forge thinks that the strata on the north of the Head are inverted, and that the slate found both north and south of the tillite is the same bed. From a

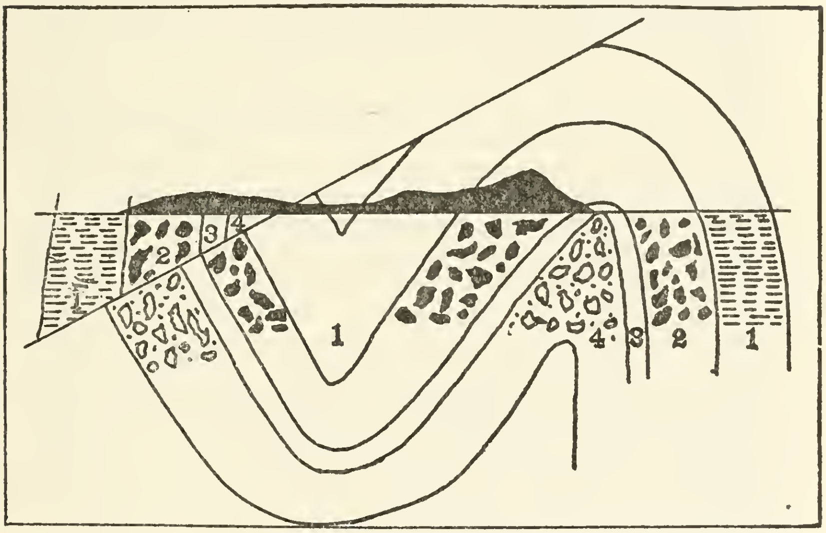

Fig. 2.— Hypothetical cross section of Squantum taken at right angles to the strike at Squantum Southeast. 1, Cambridge slate; 2, Tillite beds; 3, Lower slate; 4, Roxbury conglomerate.

study of the Atlantic locality and a comparison of the beds there with those at Squantum Head I have come to a different conclusion. It is necessary to recall the order of the beds at Atlantic. In the midst of the tillite at Atlantic there is an intercalated bed of gravel of small thickness. Near the middle of the main tillite at Squantum Head there is an intercalated bed of gravel from 15 to 30 feet thick. Under the main tillite formation at Atlantic there is a bed of sandstone about twenty-five feet thick. There is a bed of sandstone of about the same thickness on the north side of Squantum Head in contact with the main body of the tillite. Under the tillite at Atlantic there

is, in all probability, as previously shown, another bed of tillite. At Squantum Head a bed of tillite lies to the north of the sandstone. Under the tillite at Atlantic there occur contorted slate and sandstone layers with a predominance of slate. Just north of the tillite at Squantum Head contorted slate with a few sandstone layers appear. Now these beds are not duplicated at Squantum Head as they should be if doubled by folding. The order is what it should be if the beds were not doubled. It is true that such intercalated beds as these are very variable, and a bed in one outcrop might not correspond to a similar bed similarly placed in another outcrop, but the close correspondence of these beds at Atlantic and Squantum Head is more likely to mean a similar order of deposition, and the chances of coincidence are rather small.

Slate layers, or "nests" are found, and also a few small fragments of slate. These layers or "nests" of slate may be found in the first few feet of tillite on both the north and the south sides of the Head. This deposition would be possible either in an advance, or retreat, or stationary condition of the ice, so it might mean either top or bottom, and could not be limited to one or the other. If there is no duplication of beds by folding the thickness of the tillite is 600 feet, otherwise 300 feet.

There is some evidence of floating ice at Squantum Head, in boulders found in the slate. Plate **7** shows such a boulder. This one is of amygdaloidal melaphyre twenty-seven inches long and fourteen inches wide, and was found at the western extremity of Squantum Head near the contact of the tillite with the slate.

Shearing has been very intense at Squantum Head, producing a cleavage with sharp dip to the northeast.

Criteria found:— A, B, C, D, E, F, G, H, J, K, L, M, N, O.

Locality 14. Brighton. In a vacant lot west of 55 North Beacon Street, there is an outcrop which has been a puzzle to local geologists. The strike at this locality is E 8° S, and the dip 28° N. The matrix, which is less abundant than the included pebbles, varies from arenaceous to argillaceous. There is stratification, and some assorting. The thickness exposed is about seventy-five feet. The pebbles are mostly rounded with a few angular and subangular examples. No striated pebbles have been found. Slate fragments abound. Mansfield (1906, p. 75) writes as follows in regard to this outcrop:—"This ledge has given rise to some controversy because of the appearance of slate masses that resemble clastic material but are two feet or more in length and nearly a foot in width. It has been maintained on the

one hand that the slate masses are pebbles and on the other that they are pockets of slaty material laid down during the deposition of the conglomerate."

The slate masses referred to above are very similar to the slate lumps in the beds under the tillite at Atlantic. I consider their origin to be similar; disruption by moving ice and transportation by a glacial stream would explain it. No undoubted tillite has appeared north of Squantum Head and Roslindale, but clay fragments could have been transported by glacial streams beyond the ice-front for some distance. It is difficult to understand how clay particles could have been deposited in isolated pockets in so swift a stream as is indicated in this exposure by the size of the pebbles and boulders. Some of the boulders measure over a foot in diameter.

Cleavage is found at this exposure. It does not appear that this rock is tillite.

Locality 15. Waban. About half way between Eliot and Waban railroad stations there is an outcrop on the south side of the track. The strike is N 38° E, and the dip 53°N., as determined from overlying slate. This rock is not tillite but has every appearance of being on the tillite horizon. It is a very coarse conglomerate. The largest boulders are at least two feet in diameter, and are of angular, subangular, and rounded shapes. Melaphyre tuff appears to underlie this conglomerate. Above the conglomerate are beds of sandstone transitional to a thick body of slate, which appears to be the Cambridge slate. This very coarse conglomerate may well be outwash material from the glacier. It is several miles west of the most westerly outcrop of tillite.

Locality 16. Moon Island. At the most eastern extremity of Moon Island, which is, as a matter of fact, artificially connected with Squantum by a viaduct, there is an outcrop of the tillite. The strike is N 70° E, and the dip about vertical. The matrix is very fine suggesting the lower part of a tillite bed. There is no stratification and the included rock fragments are mostly angular, and subangular. No striated pebbles have been searched for. Some intercalated beds of sandstone and conglomerate may be seen. As this place was found very recently it does not appear on the locality map, and the criteria for tillite are not yet as complete as possible. Moon Island is a drumlin, and at the tillite outcrop well-exposed till lies on the tillite.

Criteria found:— A, B, C, D, J, K, L.

Locality 17. Huit's Cove. At Huit's Cove, Hingham, on the east shore of Weymouth Back River, there is an exposure of the very top

of the tillite and transition-beds and the uppermost part of the slate formation. The strike here is N 12° E, and the dip 70° N. The tillite exposure proper is very small and little can be said of it. The matrix of the tillite is sandy. The pebbles and boulders are angular, subangular, and rounded. The transition-beds are very much like those at Squantum Southeast: — large boulders and slate fragments mingled in an unstratified mass, with here and there thin layers of sandstone. An ice-rafted boulder was extricated from the slate, and many more may be seen.

Melaphyre appears about fifteen feet below the tillite, but whether as a flow, dike, or sill has not been satisfactorily determined.

Crosby studied this locality some years ago and wrote (1894, p. 249) as follows concerning the tillite: — "The pebbles are of all sizes up to a yard or more in diameter, the largest observed being a boulder of coarse granite over 5 feet in length. Furthermore the various sizes are jumbled together promiscuously without evident assorting or stratification, looking not unlike an indurated till or boulder clay." Crosby discovered some exotic limestone here, which he thinks came from the north. He did not prove his conclusions, however, on this point (Crosby, 1894, p. 265–266).

Cleavage is well marked.

Criteria found: — A, B, C, D, F, J, L, M, N, O.

Locality.— Arnold Arboretum. While the proof of this paper was in press, I discovered a large tillite locality in the Arnold Arboretum north of Peters Hill. It is the ridge covered by evergreens on the eastern margin of the Arboretum grounds. This is along the same strike as Locality 3, but farther northeast. No contacts with other beds have been seen, so it is impossible to obtain strike and tip. Criteria observed during one visit: — A, B, C, D, J, M.

Review of localities with criteria.

The list of localities on the following page with the criteria of tillite found at each, are arranged as nearly as possible according to the extent of outcrop, and favorable conditions for search.

The list below shows that where there is ample opportunity, abundant criteria are usually found. It must be noted that a thorough examination of some outcrops has been impracticable as yet, owing to location in private grounds or cemeteries. Other outcrops are so limited in extent that they show only the presence of the formation.

This will explain why some of the descriptions give so few glacial characters, and does not mean that such an outcrop would not reveal many more glacial characters if opportunity were granted to hammer and blast.

In spite of the small outcrops and those which I have not been able to investigate properly, the average percentage of criteria for all localities so far as the present investigation has gone, is slightly over 61%. Taking the first five of the localities given in the list, and the percentage of criteria is 80%. The best locality of all, Squantum Head, gives a percentage of 93%. A further search for striated pebbles by the blasting method would probably raise these percentages materially. So far nothing but geological hammers and chisels have been used. The striated rock-floor or pavement is entirely wanting. There is no prospect of finding this on account of the nature of the beds underlying the tillite.

Locality	12.	Squantum Southeast:—	A,B,C,D,E,F,H,J,K,L,M,N,O.
"	13.	Squantum Head:—	A,B,C,D,E,F,G,H,J,K,L,M,N,O.
"	3.	Roslindale:—	A,B,C,D,F,G,H,J,K,L,M.
"	1.	Hyde Park:—	A,B,C,D,E,F,G,H,J,K,L,M.
"	10.	Atlantic:—	A,B,C,D,F,H,J,K,L,M.
"	5.	So. Forest Hills:—	A,B,C,D,J,L.
"	9.	Franklin Field:—	A,B,C,D,E,F,G,H,J,K,L.
"	11.	Atlantic-Squantum Kn:—	A,B,C,D,J,K,L,M.
"	17.	Huit's Cove:—	A,B,C,D,F,J,L,M,N,O.
"	16.	Moon Island:—	A,B,C,D,J,K,L.
"	8.	Morton St:—	A,B,C,D,F,H,J,L,M.
"	6.	Forest Hills Cemetery:—	A,B,C,D,J,L,M,O.
"	2.	Milton Upper Mills:—	A,B,C,D,F,J,L.
"	4.	Roslindale:—	A,B,C,D,F,J,L.
"	7.	New Calgary Cemetery:—	A,B,C,D,J.

In view of the sum total of the evidence found in these different localities, I am forced to the opinion that there is true tillite in the Boston Basin. No other theory explains the evidence so far brought to light.

Doubtful localities.

About 500 feet northwest of Canterbury Street on Morton Street southeast of Forest Hills Cemetery, there is a conglomerate outcrop.

In an open field 300 yards south of Walkhill Street and one fourth of a mile southeast of Harvard Street there is an outcrop of slate, sandstone, and perhaps tillite.

On Blue Hill Avenue opposite Hazelton Street, just north of Walkhill Street, there is an outcrop of slate and an unstratified conglomeratic mass resembling tillite. Other doubtful deposits are as follows: —

On railroad between Wollaston and Quincy.

Black's Creek, one fourth mile west of railroad.

North Quincy, one half mile northeast of Atlantic station.

Between Florence St. and Hyde Park Avenue, near Mt. Hope station.

Cleavage.

As noted in the description given of the tillite, evidence of intense shearing is found in every locality. The cleavage dips, as a rule, in a northeasterly direction. The shearing is beautifully shown in some of the pebbles from the tillite, which have been split in two and the parts turned as if on a pivot. In a boulderet found at Squantum Head one half has been sheared from the other about one third of an inch at one end, while at the other end only slight displacement has been effected. Some of the pebbles have been indented, and others flattened and stretched. A great many have a puckered or wrinkled appearance suggesting flow-effects. Striations due to diastrophic movements may be found frequently and are entirely different from the glacial striae. Almost all the surfaces of the rock fragments in the tillite have been thus affected in some manner. With all the shearing, and other diastrophic movements which the pebbles in the tillite have been through it is not to be wondered at that glacially striated pebbles and boulders are rarely found. Occasionally one of the surfaces of a pebble has been so placed in the matrix of the tillite as to escape the violent diastrophic movements.

Some of the tillite exposures have been weathered and it is nearly useless to look for striae in these. At Hyde Park where Dr. La Forge found the best striated pebble yet brought to light, the rock has been freshly blasted and there is more hope of a successful search. There is also an advantage here in a search for striations, in that the bottom of the tillite is exposed. As mentioned above, till contains finer materials and more striated pebbles at the bottom than at the top (Stone, 1899, p. 29–30). Wherever the bottom of the tillite has been found the matrix is much finer than in the places where the top is exposed. The difficulties experienced in extricating pebbles from the fresh matrix of the bottom of the tillite has been very great. Most of those taken out have been broken in many fragments. All of the striated pebbles but one were found near the bottom of the

tillite. Until some outcrop is discovered where cleavage is absent, or much less than at any exposure yet found, it is not likely that many pebbles with glacial striae will be found.

The mud-flow idea.

Stanislaus Meunier tried to prove that the till of Switzerland was of mud-flow origin. He did not prove his theory for Switzerland and if he had been familiar with the immense areas of till in North America he might have come to a different conclusion. That till does flow under the ice when full of water, no glacial geologists will deny. There is no reason why it should not flow under such tremendous pressures, and flow-structure in till is often found. (Meunier, 1899).

The mud-flows most commonly known are composed of mud and disaggregated rock. The rocks from which flows are most likely to come are shales or slates or argillaceous schists. Granite and sandstone or conglomerate would not be so apt to flow even in a disintegrated condition. Mud-flows of this kind require a rather steep gradient, and are limited to comparatively small areas. The materials in the tillite under discussion are fresh and angular, showing no weathering, and are not of the kinds found ordinarily in mud-flows. There is no evidence of a steep gradient in the Roxbury series. The area of the tillite is more than 100 square miles, so far as known by outcrops and allowance for folding. The total original area was probably several hundred square miles or even more.

The mud-flows of volcanic origin are usually composed of a large amount of volcanic materials, such as pumice, ash, scoria, bombs, lapilli, etc. They are also, ordinarily, of comparatively small dimensions. In the tillite no such evidence of a volcanic mud-flow has been found.

The volcanic action, however, near the tillite horizon shown in the lava flow at Brighton and certain other places, may have no other effect than to cloud, for many, the whole issue of the glacial origin of the Roxbury series. Torrential waters as well as mud-flows are common in volcanic eruptions and some volcanic materials are found in the tillite, although the quantity is negligible when compared with the non-volcanic materials. In some regions glacial deposits are made up chiefly of volcanic ejections. In Glaciers of North America Prof. I. C. Russell quotes Dr. C. Willard Hayes as follows:—"The moraine in front of the Klutlan is the largest accumulated by any of the interior glaciers. It is composed very largely of the white volcanic tufa

already described, but with this are mingled many angular fragments of amygdaloidal lava and a few of granite and gneiss. Much of the moraine has been removed by streams flowing from the glacier, but remnants 2000 feet or more in thickness extend nearly across to the highland north of the valley." (Russell, 1901, p. 106).

Although striated rock fragments might be found in a mud-flow, I have yet to find a reference in the literature to such, from an actual mud-flow. Even if striated stones were found, it is not likely that all the other evidence of glaciation would be found. Those who would have the tillite under discussion a mud-flow, have also the *onus probandi* on their side.

The age of the Roxbury series.

The exact age of the tillite is still uncertain. The lithological characters of the Roxbury series resemble closely those of the Carboniferous and Permian of the Narragansett and Norfolk Basins. The Roxbury series, which consist of the Roxbury conglomerate, the Squantum tillite, and the Cambridge slate, is newer than the Cambrian as proved by pebbles in it of the granite which cuts the Cambrian. The Roxbury series lie, without much doubt on the same granitic surface of erosion which underlies the Carboniferous of the Narragansett and Norfolk Basins.

All that can be said at present is, that the tillite is of Permo-Carboniferous age. The fact that the Permian glaciation was so widespread, and that new evidence of it is coming in so rapidly, makes it very probable that the tillite is of Permian age. No fossils of determinative value have been found, although Burr and Burke did find a fossil tree-trunk in the Roxbury conglomerate proper. (Burr, H. T., and Burke, R. E., 1900, p. 179–184).

History of the tillite.

A study of the sediments of the Boston Basin gives some idea of the physiography of the region, during late Carboniferous or Permian times. The area in which the sediments were deposited extended far and wide beyond the present limits of the deposits. That the area of deposition was low relatively to the surrounding country is certain, but that it was at sea-level is not so easily determined. Towards the close of deposition the land must have been subsiding as shown by the thick bed of slate over the tillite. In order for till to be

preserved as tillite, it must ordinarily be on a surface which is subsiding at or soon after the time of the retreat of the ice-sheet. Any till deposit above sea-level on a stationary or rising surface would almost invariably be eroded long before later subsidence could remove it beyond the wear and tear of the elements. Whether the slate above the tillite is of marine or fresh water origin it is not possible at present to say. No clearly marine fossils have been found in it, and so far as this negative evidence goes it is more probable that this slate is of lacustrine origin. The absence of fossils, however, does not settle the question. Marine life in the Permian seas was scarce or wanting altogether in many places, and furthermore fossils are not found everywhere in the marine clays of Massachusetts and Maine and other places where marine clay of Pleistocene age outcrops. If volcanoes were situated then as now near the continental margins, the sea might not have been many miles away, for volcanic action was associated with the deposition of these beds as shown by melaphyre flows in several places in the Basin. According to Bailey Willis (1909, p. 403–405) land extended at least 100 miles in a southeasterly direction from Boston and probably much farther than this. That there was high land to the southeast appears probable also from a study of the tillite. The evidence so far points to a southeasterly origin for the ice which formed the tillite. A discussion of this question of direction comes naturally in the history of the appearance of the tillite as shown best in the Atlantic exposure, and in a study of some features of the tillite found at the southeastern Squantum exposure.

The Roxbury conglomerate proper at Atlantic exposes a thickness of about 520 feet. The lowest part shows rather small pebbles averaging about one inch in diameter. Farther up the pebbles increase in size gradually, while in the transition-beds below the tillite the pebbles are larger, averaging about four inches. It would seem very probable that this gradual increase in the size of the pebbles heralded the coming ice-sheet by wetter conditions or by a shorter distance from the source, as the ice drew nearer. If the larger size of the pebbles was due to more water and greater velocity, the pebbles should be as rounded as formerly, but if the approach of the ice was the cause of the size, the pebbles should be more angular as well as larger. The latter appears to be the case.

Above the Roxbury a sandstone bed was formed, indicating slower stream-action. A bed of conglomerate was then laid down, indicating swifter stream-action. Another sandstone bed was then deposited. At this point a new phenomenon is met with. Above this last men-

tioned sandstone comes a conglomeratic mass which differs from the Roxbury in having the fragments and lenticular layers of slate, mentioned above in the description of this locality. From a study of this bed I infer that the ice had come near when these fragments of clay were deposited. Just above this bed come about forty-seven feet of slate and sandstone layers with ripple-mark and some boulderets from eight to ten inches in diameter. At this time the ice must have made a temporary halt or retreat. At least deeper or slower water conditions prevailed. Certain layers in this slate bed are contorted, and immediately above and below these layers there are no signs of contortion. The tops of the arches are eroded, thus proving that the contortions were made while the deposition of the slate beds was going on. The ripple-mark suggests a stream of slow speed which might very well have eroded the tops of these folds. Above these slate and sandstone layers occurs another conglomeratic mass with more slate fragments and probably a bed of tillite. At this place there are no good exposures for fifty or sixty feet; but tillite, which I believe to be *in situ* outcrops, in one place. There is no tillite immediately to the north or northwest of this spot, so it does not seem probable that this outcrop is a boulder. Above this horizon comes a bed of sandstone about twenty feet thick. In the midst of this sandstone are some very thin layers of conglomerate and a few slate fragments, one of which measures eight by ten inches. These last mentioned beds indicate another advance and retreat of the ice-sheet. The relatively thick sandstone bed shows that the ice retreated for some distance and might or might not indicate an interglacial epoch.

Above this sandstone comes the main body of the tillite. The difference between the tillite and the water-laid conglomerate which contains the slate lumps is obvious. The contact between the sandstone and the tillite is very ragged, showing disruption of the sandstone. The tillite pierces the sandstone as if pushed into it. With the exception of very thin layers of slaty material no intercalated beds are met with in this exposure for about 150 feet, when a bed of conglomerate and sandstone is found not over two feet thick. It is probable that this bed is the equivalent of the bed of coarse gravel found at Squantum Head and indicates a retreat of the ice. Above this bed the tillite is continuous as far as the outcrops extend, but it is evident that not much more than one half of the tillite is exposed at this locality.

To obtain an idea of the sequence of events near the top of the tillite a study of the exposure at the southeast Squantum locality is best, as the section is almost all exposed to view for several hundred

feet along the shore. Of this exposure only the uppermost part will be considered.

Commencing on the little high-tide island opposite the end of the road, thin intercalated beds of sandstone and slate are found. One of these beds has a plication in an east-west direction which may have been made by ice-push. It does not seem probable that this plication was caused by diastrophic movement, not only because the movement was at right angles to the main direction of folding, but also because there are no signs of plication above or below this bed. It is of course possible that there was diastrophic movement transverse to the main direction of folding, but if this had been the case here it would seem that there should be some evidence of it above and below the plication.

Above this first intercalated bed, near the top of the tillite, there are two more similar beds, and between each, undoubted tillite. In places there are very fine layers of slaty material not more than one sixteenth of an inch thick. Pebbles are pressed into these thus cutting them off and deforming them. These tiny clay-threads suggest melting of the ice and trickling of water laden with clay, between the ice and the till.

A large block of pink granite, in the tillite on this island, six feet long and one foot wide, is important in showing transportation without wear. (Plate 9). The block is angular. It is not easy to see how this block could have been transported in its present fresh condition by any other agency than an iceberg or a glacier.

Returning to the main land and proceeding in a southerly direction along the shore, the transition-beds from the tillite to the main slate-body can be studied with ease. The beds intercalated in the tillite grow in thickness towards the top, suggesting longer retreats of the ice each time. The proportion of pebbles to matrix increases, and slate fragments of all shapes and sizes make their appearance. The tillite now suggests very thin ice acting for short periods, for the pebbles are very abundant. Retreats and advances were of shorter duration. The reappearance of the slate fragments at the top of the tillite is to be explained, I believe, in these advances and retreats of the ice. The ice retreated, and deposits of gravel, sand, and clay were made on the ground left vacant by the retreat. Again the ice advanced, ploughing up the beds formed at its front and making a new till composed of parts of gravel, sand, and clay-beds.

Disrupted sandstone and slate beds come above this slate lump horizon, and then appears the main body of the slate, the highest member of the series in the Boston Basin. The ice had then retreated

permanently from the Basin, and the land had subsided, and continued to subside until several hundreds of feet of clay had been deposited.

The direction of movement of the glacier which produced the tillite is most important. There are a number of considerations which indicate a direction from the southeast to the northwest. Though not certainly due to ice thrust, the plication of the intercalated bed mentioned above, points to such a direction of movement. Again in the description of this locality (page 155) it should be noticed that the beds intercalated in the tillite strike at an angle of from eight to ten degrees more east than the main body of the slate higher up. This must mean either a diastrophic change in the attitude of the beds, or that the intercalated beds sloped downwards towards the level of the water in which the slate was deposited. There is no evidence of an eroded zone between the transition-beds and the slate, so it does not appear that there is any unconformity. The beds in question slope from the east towards the west. According to Prof. James Geikie (1895, p. 24), beds intercalated in till are diagonal and not as a rule horizontal, and slope towards the ice-front. It would appear that the beds in the tillite at Squantum Southeast dipped westward, and if this was the case, and the difference in strike is not due to diastrophic movement, there would seem to be good reason for believing that the ice came from an easterly direction. Then again, a consideration of the slate fragments might also indicate an east-west direction of ice movement. In the tillite at Hyde Park, Milton Upper Mills, Roslindale, I have not observed slate fragments. At Squantum, and Atlantic the rock fragments in the tillite show a majority of pink granite, with melaphyre and quartzite coming next in abundance. If the ice had come from the north, the granite fragments could be explained, but not the melaphyre. If it had come from the west, the melaphyre fragments could be explained, but no pink granite of the variety found in the tillite is known in that direction. If the ice came from the south the pink granite could be accounted for, but not the melaphyre. If the ice came from the southeast, however, both the pink granite and the melaphyre are explained, for at Nantasket, Cohasset, and Hingham these rocks are found *in situ*. The fact that the largest boulders found in the tillite are of pink granite and melaphyre, and that these are found together, suggests a place of origin for both near the same locality. I have not forgotten that Pleistocene drift may hide some outcrops, and that the above suggestion cannot be proved, but so far as known outcrops go, it is a legitimate speculation, and when joined to the other evidence of the direction of ice movement appears

logical and what would be expected if the ice came from the southeast. Another indication of the direction of ice movement is found in the limited westward extension of the tillite. To the west beyond Roslindale no true tillite has yet been found. Southwest of Mt. Benedict in the woods there is a layer of very large boulders in the conglomerate. One of them measures over three feet in diameter and most of them are over two feet. There is a suggestion here of outwash materials and swift water. At Waban in what appears to be the tillite horizon there are more large boulders, but no tillite. To the north of Squantum Head and Roslindale no undoubted tillite has been found. All of these considerations point to an easterly or southeasterly place of origin. The fact that no terminal moraine has been found is no proof that there was none. The width of a frontal moraine belt varies from a few feet to twenty miles for a continental glacier. A wide belt would probably appear somewhere in these highly folded strata of the Boston Basin, but a narrow belt might easily have been folded under or already eroded and thus lost to sight. Outwash materials, however, would extend for miles beyond the terminal moraine, and that some of the coarse gravels west of Roslindale are of such origin appears possible.

It is impossible to say whether the glacier which formed the tillite was of the continental or piedmont type. The large thickness of the tillite might indicate either, for thick till is not limited to continental glaciers, but is found in the low lands of the Alps at the present day. The thickest till is almost always found in the valleys (J. Geikie, 1895, p. 24). The boulders and fragments of limestone found by Crosby at Huit's Cove, Hingham, in the tillite, seem to be real exotics, and this might indicate that the ice came from some distance. It is necessary to suspend judgment on this question of type of the glacier. The Malaspina glacier is about seventy miles long and twenty-five miles wide. A glacier of this size would answer all the requirements of the discoveries in the Boston Basin. The extent of the tillite precludes anything smaller than a piedmont glacier.

In the vicinity of Squantum and Atlantic the tillite is seen to be made up of three separate beds divided by the two intercalated beds mentioned above. If the intercalated beds near the top are considered, the tillite is divided still farther. Whether the two main intercalated beds indicate interglacial epochs is a question of importance. That such beds indicate milder conditions there can be no doubt, but that such milder conditions would mean an interglacial epoch of long duration is more difficult to prove. All that can be said,

therefore, in regard to these two beds in the tillite is, that they prove milder conditions and temporary retreats of the ice-sheet, and that the cause of glacial periods fluctuated in the distant geological past much as it did during the Pleistocene period. It would be a difficult matter even with the aid of fossil plants, to prove an extended interglacial epoch in such a limited deposit as that found in the Boston Basin, unless other evidences of interglacial conditions were present.

Acknowledgements.

It was through Dr. Laurence La Forge that I first saw the rocks discussed in this paper. He pointed out to me localities 1, 2, 5, 7, 12, 14, 15, 17. During trips with him I obtained a clear insight into the structure and stratigraphy of the rocks in the Boston Basin as determined by him. Subsequent research independently corroborates the ideas he held in 1910, with the exception of his interpretation of the structure of Squantum. The light which my recent work on this locality has thrown, obliges me to differ from him in regard to the structure of this section of the field, and the reasons for my difference of opinion have been given in the description of Locality 13. Prof. J. B. Woodworth has given me invaluable criticism and advice. Acknowledgements are also due to Profs. W. M. Davis, A. C. Lane, J. E. Wolff, Ellsworth Huntington, and George R. Mansfield, to Drs. F. H. Lahee, and Arthur Keith, to Mr. Burton M. Varney, and Mr. George M. Flint.

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PLATE 1.

Tillite at Hyde Park.

Behind the store house of the Becker Milling Machinery Co. Note the unstratified, unassorted nature of the rock, and the cleavage. The rock is comparatively fresh.

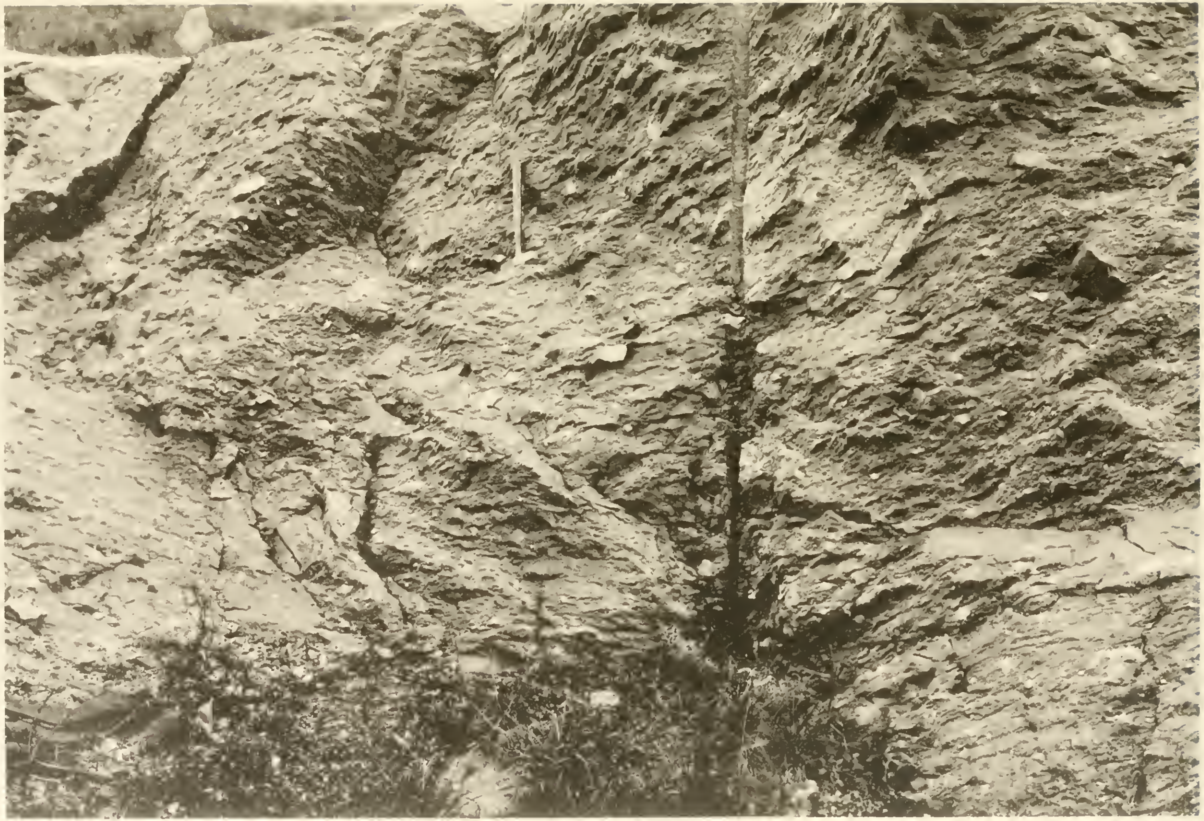


PHOTO. BY R. W. SAYLES

PLATE 2.

Striated pebble from Hyde Park.

Shows striae in numerous directions. On the right is the typical concave fracture due to pressure of ice. A crack due to shearing is shown above, dipping at an angle of about 60° towards the right. Another crack crosses this one and dips in the opposite direction. The latter was made in extracting the pebble from the matrix. There is also a fresh fracture on the upper left. Note the wide type of striae. The pebble is quartzite. Found in tillite matrix by Dr. Laurence La Forge, in the presence of Dr. Ellsworth Huntington and the writer, 11 July, 1910. A trifle under natural size.

STRIATED PEBBLE

PLATE 3.

Pleistocene pebble showing wide striae.

Found by Prof. J. B. Woodworth at Pondville, Mass., in washed gravel one hundred and fifty feet from an ice-front; shows the faintness of the grooves and the wide type of striation; compare Plate **2**. Natural size.

PHOTO. BY TURPIN

PLEISTOCENE PEBBLE SHOWING WIDE STRIAE

PLATE 4.

SEA CLIFFS ON THE SOUTH OF SQUANTUM HEAD.

A large outcrop of tillite. The rock is much weathered.

PHOTO. BY LINCOLN

TILLITE AT SQUANTUM HEAD

PLATE 5.

TILLITE AT SQUANTUM HEAD.

A small detail section of a part of the exposure shown in Plate 4. The exact position is indicated by the hammer. Note the angular, subangular, and rounded rock fragments in an argillo-arenaceous matrix.

PHOTO BY LINCOLN

TILLITE AT SQUANTUM HEAD

PLATE 6.

Tillite at Squantum Head.

This exposure is at the base of the cliff on the north of the Head. The cleavage on the right appears like slate on account of the argillaceous nature of the matrix.

PLATE 7.

Boulder in slate at Squantum Head.

Amygdaloidal melaphyre boulder in slate showing evidence of ice rafting. Several other cases of this kind may be found near Squantum Head. This boulder was found at the most western part of the Squantum Head locality. Size of boulder 20 x 9 inches.

PHOTO. BY R. W. SAYLES

BOULDER IN SLATE AT SQUANTUM HEAD

PLATE 8.

Large slate fragment in tillite.

This large slate fragment was dragged upward into the tillite from a bed of slate intercalated in the tillite. The bed shows disruption as if by moving ice. Squantum Southeast.

PHOTO. BY R. W. SAYLES

SLATE IN TILLITE AT SQUANTUM SOUTHEAST

PLATE 9.

Granite block in tillite at Squantum Southeast.

Angular block of pink granite. There is no evidence of movement by flowing water. Dimensions 6 ft. x 1 ft.

PHOTO. BY R. W. SAYLES

GRANITE BLOCK IN TILLITE AT SQUANTUM SOUTHEAST

PLATE 10.

Pebbles from the tillite.

Beginning at the upper left hand corner the pebbles from left to right are:— quartzite pebble from Roslindale showing subangular shape and fracturing; granite pebble from Roslindale showing subangular shape and concave fractures; melaphyre pebble from Squantum Head showing bevelling and striae; quartzite pebble from Franklin Field shown to better advantage in Plate 11; quartzite pebble from Roslindale showing bevelling, faint striae, and concave fractures; here an attempt was made to show ice bevelling on both sides of a central ridge, the ridge is indistinct in this picture. The last specimen was found by Dr. Arthur Keith of the United States Geological Survey and considered by him at the time as of glacial origin.

PHOTO. BY TURPIN

TYPICAL PEBBLES FROM THE TILLITE

PLATE 11.

EBBLE FROM TILLITE AND PEBBLE FROM TILL.

On the left is a quartzite pebble from the tillite at Franklin Park, showing one blunted end, concave fractures, striae, and ice shaping. On the lower surface there are a number of striae running in different directions. This pebble has been slightly squeezed at the pointed end; the contact of the matrix with the pebble may be seen on the lower surface. A small piece of matrix adheres to the pebble on the upper left hand side.

The pebble on the right is the type found very commonly in till. This one was found at Mystic in the Pleistocene till of a drumlin. In general characters it is very much like the pebble from Franklin Park.

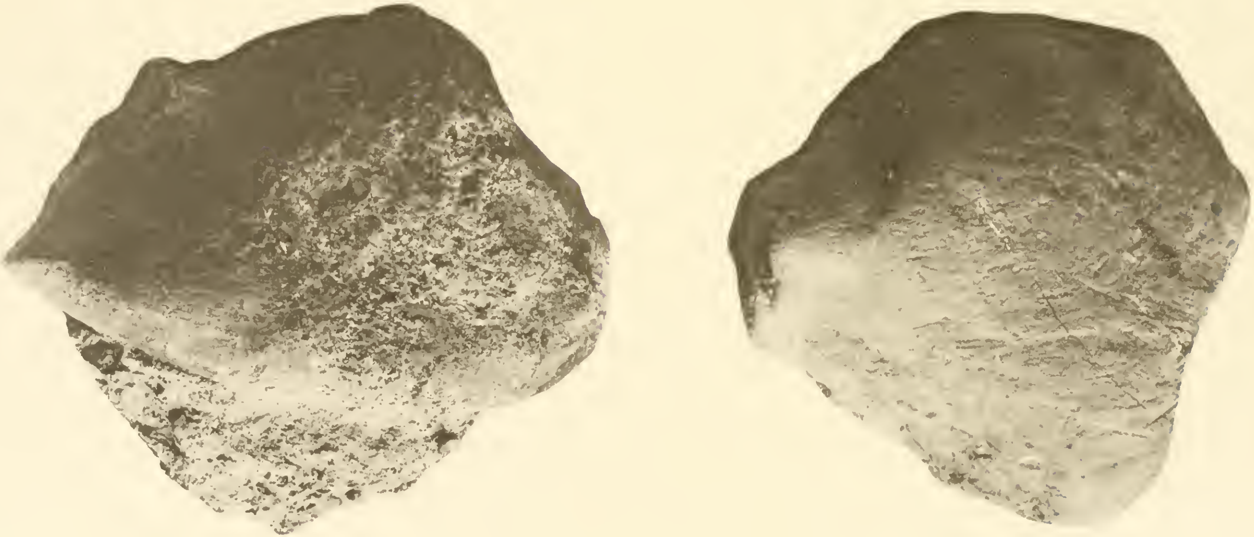


PHOTO. BY TURPIN

PERMIAN AND PLEISTOCENE PEBBLES

PLATE 12.

Locality map.

Fig. 1. Hyde Park; across the street from the Becker Milling Machinery Co.

Fig. 2. Milton Upper Mills; about $\frac{1}{10}$ of a mile east of Blue Hill Avenue, on Eliot Street, 200 feet from the road, in the woods on the left.

Fig. 3. Roslindale, about 50 feet east of the junction of Centre and Weld Streets.

Fig. 4. Roslindale; about $\frac{1}{4}$ of a mile southwest of the first Roslindale exposure.

Fig. 5. Forest Hills; about 300 yards south of the Cemetery, and 100 yards east of the trolley line.

Fig. 6. Forest Hills Cemetery; the most southeasterly exposure of rock in the Cemetery.

Fig. 7. New Calgary Cemetery; $\frac{1}{5}$ of a mile south of Walkhill Street on Harvard Street, close to the fence on the left.

Fig. 8. Morton and Canterbury Streets; Morton Street east of Forest Hills Cemetery, about 50 feet south of Canterbury Street.

Fig. 9. Franklin Field; at the junction of Blue Hill Avenue and Harvard Street.

Fig. 10. Atlantic; $1\frac{1}{2}$ miles southwest of the aviation field, in a wooded cow pasture.

Fig. 11. Squantum Knoll; on a little wooded knoll to the right of the highway which connects Atlantic and Squantum.

Fig. 12. Squantum Southeast; at the end of the road which extends farthest east on Squantum. Also on a little high-tide island near the shore.

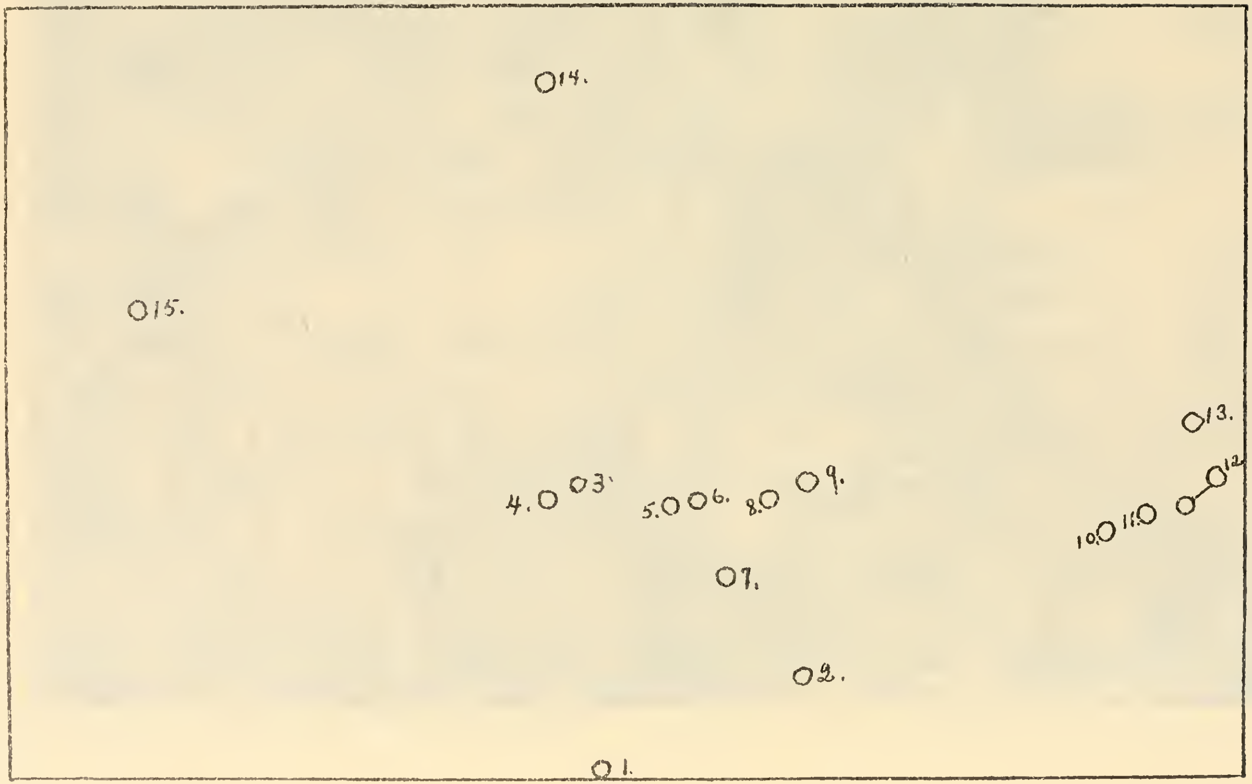
Fig. 13. Squantum Head; at the Head, along the shores, and on the hill.

Fig. 14. Brighton; in a vacant lot west of 55 North Beacon Street.

Fig. 15. Waban; about half way between the Eliot and Waban railroad stations, to the south of the track.

Note. The map was printed before Locality 16 was found.

Locality Finder



LOCALITY MAP

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LOUIS CABOT. Immature State of the Odonata, Part IV.
E. L. MARK. Studies on Lepidosteus, continued.
" On Arachnactis.
A. AGASSIZ and C. O. WHITMAN. Pelagic Fishes. Part II., with 14 Plates.
H. L. CLARK. The "Albatross" Hawaiian Echini.

Reports on the Results of Dredging Operations in 1877, 1878, 1879, and 1880, in charge of Alexander Agassiz, by the U. S. Coast Survey Steamer "Blake," as follows:—

A. MILNE EDWARDS and E. L. BOUVIER. The Crustacea of the "Blake."
A. E. VERRILL. The Alcyonaria of the "Blake."

Reports on the Results of the Expedition of 1891 of the U. S. Fish Commission Steamer "Albatross," Lieutenant Commander Z. L. Tanner, U. S. N., Commanding, in charge of Alexander Agassiz, as follows:—

K. BRANDT. The Sagittae.
" The Thalassicolae.
O CARLGREN. The Actinarians.
R. V. CHAMBERLIN. The Annelids.
W. R. COE. The Nemerteans.
REINHARD DOHRN. The Eyes of Deep-Sea Crustacea.
H. J. HANSEN. The Cirripeds.
" The Schizopods.
HAROLD HEATH. Solenogaster.
W. A. HERDMAN. The Ascidians.
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JOHN MURRAY. The Bottom Specimens.
P. SCHIEMENZ. The Pteropods and Heteropods.
THEO. STUDER. The Alcyonarians.
—— The Salpidae and Doliolidae.
H. B. WARD. The Sipunculids.

Reports on the Scientific Results of the Expedition to the Tropical Pacific, in charge of Alexander Agassiz, on the U. S. Fish Commission Steamer "Albatross," from August, 1899, to March, 1900, Commander Jefferson F. Moser, U. S. N., Commanding, as follows:—

R. V. CHAMBERLIN. The Annelids.
H. L. CLARK. The Holothurians.
—— The Volcanic Rocks.
—— The Coralliferous Limestones.
S. HENSHAW. The Insects.
R. VON LENDENFELD. The Siliceous Sponges.
H. LUDWIG. The Ophiurans.
G. W. MÜLLER. The Ostracods.
MARY J. RATHBUN. The Crustacea Decapoda.
G. O. SARS. The Copepods.
L. STEJNEGER. The Reptiles.
C. H. TOWNSEND. The Mammals, Birds, and Fishes.
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Reports on the Results of the Expedition of 1891 of the U. S. Fish Commission Steamer "Albatross," Lieut. Commander Z. L. Tanner, U. S. N., Commanding, in charge of Alexander Agassiz.

Reports on the Scientific Results of the Expedition to the Tropical Pacific, in charge of Alexander Agassiz, on the U. S. Fish Commission Steamer "Albatross," from August, 1899, to March, 1900, Commander Jefferson F. Moser, U. S. N., Commanding.

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EXPEDITION TO THE BALTIC PROVINCES OF RUSSIA AND SCANDINAVIA.

PART 1.— THE CORRELATION OF THE ORDOVICIAN STRATA OF THE BALTIC BASIN WITH THOSE OF EASTERN NORTH AMERICA.

By Percy E. Raymond.

With Eight Plates.

CAMBRIDGE, MASS., U. S. A.

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Reports on the Scientific Results of the Expedition to the Eastern Tropical Pacific, in charge of Alexander Agassiz, by the U. S. Fish Commission Steamer "Albatross," from October, 1904, to March, 1905, Lieutenant Commander L. M. Garrett, U. S. N., Commanding, published or in preparation:—

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[1] Bull. M. C. Z., Vol. XLVI., No. 4, April, 1905, 22 pp.
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[5] Mem. M. C. Z., Vol. XXXIII., January, 1906, 90 pp., 96 pls.
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No. 3.— *Expedition to the Baltic Provinces of Russia and Scandinavia, 1914.*

Part 1.— The Correlation of the Ordovician Strata of the Baltic Basin with those of Eastern North America.

By Percy E. Raymond.

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PREFACE.

The writer has been engaged since the summer of 1900, in the study of the stratigraphy and faunas of the Middle Ordovician formations of the northeastern United States and Canada. During all that time the need of a personal knowledge of the Ordovician strata of northern Europe had become more pressing, so that he was exceedingly glad of a grant from the Shaler Memorial fund which enabled him to spend several months of the summer of 1914 in Russia and Scandinavia. With the coöperation of Dr. W. H. Twenhofel, who studied especially the Upper Ordovician and Silurian strata, a rather complete, though necessarily hasty survey of the Lower Palaeozoic strata of the districts mentioned was completed between May 1 and September 30 of 1914, and large collections secured. The outbreak of the war interfered with the completion of the work as planned, and quite seriously affects the present report, since all the collections of three men during a month spent in Esthonia were in Russia at the time of the outbreak of hostilities and it is somewhat doubtful if they ever reach this country. Our conclusions on some points are therefore of a tentative nature, and if we should be so fortunate as to receive the collections, a supplementary report may be necessary.

The results of a trip of this sort are very largely dependent upon the assistance of others, and I have an unusually large number of courtesies to acknowledge. To my colleagues in the Division of Geology at Harvard University I am deeply indebted for making the expedition possible. To Prof. Charles Schuchert I owe much for advice, and for letters of introduction over a route which he had himself travelled. Mr. I. P. Tolmacev, Curator-in-chief of the Museum of the Imperial Academy of Science in Petrograd, made arrangements and secured letters which greatly facilitated our work in Russia. It was he, and the excellent assistant, Mr. Carl Lackschewitz, whom he secured to travel with us, who enabled us to work continuously and comfortably during our stay in Russia. Mr. Lackschewitz, a grandson of the celebrated Middendorf, and grand-nephew of Fr. Schmidt, in whose footsteps we were following, proved our invaluable interpreter, advisor, and business agent. To the knowledge and skill of Mr. O. Knyrko preparator at the Museum in Petrograd, I am indebted for much beautifully preserved material collected during the ten days in which he acted as guide in the region south of Lake Ladoga. To the many other gentlemen who assisted us in Russia, some of whom are named in the introduction to Dr. Twenhofel's report, I also wish to express my thanks.

Just as I write these acknowledgements comes the sad news of the death of Professor Dr. Johan Christian Moberg, but for whose kindly assistance my visit to Sweden would have been of little value. Cutting short his own field season, Professor Moberg devoted himself for almost three weeks to guiding me over the Cambrian and Silurian deposits of Scania. Without his intimate knowledge of the extremely restricted outcrops in this region, my work would have been fruitless, indeed, impossible in the restless moments of the first weeks of the war.

In Norway we were greatly indebted for guidance and hospitality to Professor Kiaer and Dr. Holtedahl who made possible a great deal of work and collecting in a very short time.. Nor must I omit an expression of my obligation to M. Pierre Pruvost of Lille for escorting me during three pleasant days spent among the Palaeozoic outcrops of the Ardennes. It is with more than usual feeling that I make these expressions of sincere gratitude to those who assisted me, especially as there is only too much cause to fear that they may never see these lines.

Finally, I wish to express my appreciation of Dr. Twenhofel's kindness in undertaking his part of the work, and of his hearty coöperation in the field.

THE ORDOVICIAN STRATA IN THE GOVERNMENTS OF PETROGRAD AND ESTHONIA, RUSSIA.

Location.

The Cambrian and Ordovician strata of western Russia outcrop in the northern parts of the Governments of Esthonia and Petrograd, forming a narrow strip about 380 miles long, extending from the island of Dago along the southern shore of the Gulf of Finland to the eastern boundary of Esthonia at the Narowa River, thence eastward inland to the Sjass River, south of Lake Ladoga, and eighty-five miles east of Petrograd. This strip is roughly triangular, having at its widest portion in Esthonia, a breadth of thirty miles, and narrowing to a point a short distance east of the Sjass. In Esthonia, west from Lake Peipus, the Ordovician is followed by the Silurian; while in the Government of Petrograd, the Devonian conceals the Silurian and overlaps successively lower and lower beds of the Ordovician, until east of the Sjass, it conceals all but a narrow band of Cambrian. This overlap of the Devonian on the Ordovician in the Government of Petrograd does not, however, indicate at all the absence of Silurian in the southern part of that district, as many geologists have believed. Throughout the whole band, the older strata dip gently to the south, a dip which they apparently received in pre-Devonian times. Thus each successively higher stratum has its outcrop in an east-west band lying southward from its neighbor, and the Devonian, lying unconformably on these beds, conceals older and older ones according to the amount of its northward extent. (Plate **1**).

Previous work.

As early as 1821 an Englishman, William Strangways, (52), published a detailed description and map of the strata in the vicinity of Petrograd, and since then various writers have described in great detail the Cambrian, Ordovician, and Silurian of this region. The principal writers on the Geology, as distinguished from the Palaeontology, have been Murchison, (35), Eichwald, (8), Schmidt, (42, 44, 45, 47), Mickwitz, (33), and Lamansky, (29). Recently Bassler, (1), has published a short resumé of the results of the work of Schmidt and Lamansky.

The palaeontologists have been particularly active in describing the Ordovician fossils of this region, as may be seen by the very long list of species given by Bassler, (1). Part of this work, on the trilobites by Schmidt, (48), bryozoans by Bassler, (1), and cystids by Jaeckel, (24), is modern, as are also descriptions of certain groups of Ostracoda, Cephalopoda, Brachiopoda, and Gastropoda by various writers. The bulk of the Brachiopoda, Pelecypoda, and corals, still await monographic treatment, though some of these groups are now in the hands of specialists.

Object of the present paper.

Although so well known and fully described, there still exist in text-books many inaccurate statements about the region under discussion and there is no modern general treatment of the whole area. For these reasons, and because previous papers are mostly in German and Russian, and without illustration, there exists in the minds of most American geologists only a very vague idea of the character of the Russian deposits, and the writer therefore feels justified in retraversing this old and well-known ground, and hoping to add something to what has previously been observed.

During the seven weeks spent in this area I was able to cross the outcrop of the Cambrian and Ordovician on the Sjass, the Walchow, and the Lawa at Wassilkowa, all south of Lake Ladoga, at Papowka, south of Petrograd, at Narwa, from Ontika south to Jewe, from Port Kunda south through Wesenberg and Taps to Borkholm, from Reval and Baltishport southwest through Kegel, Wassalem and Lyckholm to Hapsal, and also visited the principal localities on the northern half of Dago. I was thus able to see all the principal sections and type-localities and crossed the Cambrian-Ordovician belt at right angles to the strike at frequent intervals throughout the whole length of the outcrop.

Although the Borkholm and Lyckholm are considered by the writer to belong to the Ordovician they are treated only incidentally in this paper, but are fully discussed by Dr. Twenhofel (Bull. M. C. Z. **56**, no. 4).

Nature of the exposures of the strata.

Throughout the whole area underlain by the Ordovician strata the country is comparatively flat, and the majority of the hills which do

occur are composed of glacial debris. Along the whole northern boundary of the area there is an abrupt escarpment, facing northward, extending from the island of Odensholm through Baltishport and along the southern shore of the Gulf of Finland to the mouth of the Narowa, and thence across country south of Petrograd to the Sjass. Where this borders the sea it is usually very steep, often perpendicular or overhanging. In the Government of Petrograd it is a steep slope, but usually without exposures of rock except where cut by streams or by the opening of quarries. This cliff, or "Glint,"[1] is of variable height; only fifteen feet on Odensholm, it reaches its maximum height of 206 feet at Ontika in the eastern part of Esthonia, and probably averages 75 to 100 feet. The strata composing the top of this cliff are, remarkably enough, practically always the same, being the rather hard magnesian limestone of the lower part of zone C or the "Echinosphaerites" layers. Such being the case there are many excellent exposures of the part of the Ordovician below this horizon, and, where there is not too much talus at the foot of the cliff, the upper part of the Lower Cambrian is usually shown.

From Petrograd eastward, no strata of the Ordovician are exposed above the Echinosphaerites beds. The higher strata are to be found in the part of the Government of Petrograd west of the metropolis, and especially in the Government of Esthonia. These beds are very seldom seen in natural sections, being practically always uncovered only by the opening of quarries. All the quarries are of comparatively small extent and very shallow, so that there is never more than one formation exposed in any one quarry, and contacts between formations above the Kuckers have never been seen.

Over large areas in Esthonia the strata lie very close to the surface, and even very shallow ditches often penetrate the rock. Among such ditches the "Graben" on the estate of Baron Toll at Kuckers, near Jewe, is famous as the principal locality of the Kuckers formation. Many other ditches, often very small ones, were examined during this trip and often afforded the only outcrops over considerable areas.

Formational Names.

The names applied to the formations in this district of Russia bear a direct relation to the above described occurrence of outcrops. In the classification proposed by Schmidt the important divisions of the

[1] From the Danish Klint, a reminder of the settlement of this country by the Danes in the 12th century.

Cambrian and Ordovician were lettered in ascending order A to F, and many of the subdivisions designated by numbers as, C_1, C_2, C_3 and finally some of these subdivisions were further divided by Lamansky, as for instance $B_{II\alpha}$, $B_{II\beta}$ and $B_{II\gamma}$. The strata also received names suggested by their lithological characteristics or faunal contents, as for instance, B_I was also known as the "Glauconite sand" and B_{III} as the "Orthoceras limestone" or "Vaginatenkalk." The divisions from A to $C_{1\beta}$ are to be found in the escarpment, and these together received the collective name of the "Glint" but no formation in this part of the series has received a separate geographic name.

The strata above $C_{1\beta}$ are exposed as has already been explained, principally in quarries, and therefore each formation has received a name from the locality which has furnished either the best exposures or the best fossils. Thus C_2 is known as the Kuckers, E as the Wesenberg, etc.

In this particular case, both the system of lettering and the system of descriptive names is objectionable, and for the sake of uniformity the writer suggests a set of geographic names for the older formations of the series. The system of lettering fails, because A_2 and A_3 of Schmidt prove not to be Cambrian but Ordovician, thus splitting A between two great systems. There is likewise a difficulty about D_2 which will appear later. A mixed table of descriptive names, part derived from lithological and part from faunal characteristics is never satisfactory, and in this case the names seem particularly inapplicable. Thus the "Orthoceras" limestone is not by any means the only formation in Russia in which Orthoceras is abundant, and the term has not the same meaning here as when applied to Ordovician strata in Sweden or Norway. Likewise C_1 is called the "Echinosphaerites" limestone, though Echinosphaerites is equally common at some localities in C_2, C_3 and the lower part of D_1.

Description of Formations.

Cambrian.

Esthonia formation. A_1 and part of A_2 (Blauer Thon and lower part of Ungulitensand) of Schmidt. Lower Cambrian.

Since it has been so well described by Schmidt (42), Mickwitz (33), and Holm (20), the writer paid comparatively little attention to the study of the Cambrian, but examined the exposures at Reval, Port

Kunda, Ontika, Peuthof, and Papowka, and studied especially the contact of the Cambrian and Ordovician near Baltishport and at Narwa. The best section seen was at the cliff Peuthof, which is north of the station Waiwara, a few miles west of Narwa. Alternating strata of light colored sandstone and blue clay-shale were there well exposed, but the strata can be studied more in detail at Port Kunda, where Mickwitz found specimens of *Schmidtiellus mickwitzi*, the mesonacid which first afforded definite proof of the Lower Cambrian age of these strata.

It has been repeatedly stated that the "Blue Clay" underlies the sandstone of the Cambrian, but I did not find this to be the case. Everywhere the highest layer of the Cambrian appeared to be a hard, usually almost white, sandstone. The upper bed, where its thickness could be seen, was usually not over fifteen to twenty-five feet thick, and beneath it was a bed of blue clay-shale of variable thickness. Below this again one finds sandstone and alternations of shale and sandstone continue to the base of the cliff, and, according to borings in Reval and Petrograd, such alternations continue downward about 600 feet to the gneiss. The fossils have been found in the upper zones, within fifty feet of the top of the formation, and there is no reason to believe that strata of any age other than Lower Cambrian are present in this formation. The "Blue Clay" of the Lower Cambrian has received considerable notoriety, as it has often been reported as a soft, unconsolidated blue clay which could not be distinguished from clay of glacial age. Masses of this sort were seen at two places, at Papowka south of Petrograd, and on the shore at Ontika. In neither case was the clay actually in position either under or between layers of sandstone, but it lay in such a position that it could be readily conceived that it was Cambrian clay which had worked out from a layer nearby. In both cases it was very full of water, and it is probable that it represented a portion of a stratum of shale which had been worked up by the action of frost, water, and a creeping movement, until all traces of the original stratification had been destroyed. Where mined from the layers for the cement plant at Port Kunda, the clay is well stratified, and hard. It is, however, very fine grained, soapy to the touch, and a very fine plastic clay. The quickness with which it loses its stratification on weathering is probably due to its fine grain and the readiness with which it takes up water, rather than to the fact that it has never been consolidated.

In discussing the finds of "Olenellus" at Kunda and near Reval by Mickwitz, Marcou (31) proposed for the Lower Cambrian strata as

developed at these two localities the geographic name Esthonian, which may now with propriety be applied to all the Lower Cambrian strata in the whole district. Of the two localities first mentioned, Kunda, and Strietsberg near Reval, the former presents the better outcrop, and it may be taken as the type-section of the Esthonian.

Ordovician.

Packerort formation. Upper part of A_2, and A_3 (upper part of Ungulitensand and the Dictyonemaschiefer or Alunschiefer), of Schmidt. (Plate **7**).

The most instructive section of the formation to which this new name is given is to be found at the base of the perpendicular 80-foot-high-cliff upon which is built the light-house Packerort at the end of the peninsula north of Baltishport. At the base of the cliff one sees, partly in the water, eight feet of hard, almost white, coarse-grained sandstone, representing the top of the Esthonia formation. Resting upon this is a bed of conglomerate, the matrix of which is an iron-stained sandstone, and which contains well-rounded boulders ranging from a few inches up to four feet in the greatest diameter. The boulders are all of sandstone, with some small pebbles of quartz, and are very numerous, making up the whole of that part of the formation which rests upon the Cambrian. This conglomeratic layer is very irregular, and only two or three feet thick. It is succeeded by alternations of thin layers of sandstone and a very dark gray, friable, soft shale. Above this comes a very irregular layer, five to ten feet thick, of cross-bedded, coarse-grained sandstone with great numbers of *Obolus apollinis* in the upper part. Then follows a band of thin-bedded dark gray shale like that below, but in certain layers, containing great numbers of graptolites, principally *Dictyonema flabelliforme.* As these strata rest upon the undulating surface of the sandstone below they have a variable thickness, from thirteen to eighteen feet.

The conglomerate at the base of the formation was seen also along the river north of the railroad bridge at Narwa. The pebbles at that locality were all rather small, the largest seen being ten inches in diameter. The interbedding of the shale and sandstone was seen also at Asserien, and although the sandstone and shale of this formation are usually in distinct bands, these sections show that the two are intimately associated and belong to the same time. The conglomerate and sandstone indicate the shore phases of the earliest Ordovician transgression; the shale with the graptolites a later shallow water

phase. The still later deeper water limestone phase, with the Ceratopyge fauna, seems never to have reached this region.

Mickwitz fully recognized the physical evidences of an erosion period between the Lower Cambrian and the time of deposition of the Obolus sandstone, and in the preface to his paper on Obolus (33), he gives some excellent detailed sections of the Obolus sandstone. He recognized the basal conglomerate at Packerort, which he illustrated by a diagram, and he gave also a diagrammatic representation of the strongly eroded top of the Lower Cambrian sandstone at Jamburg on the bank of the Luga, east of Narwa. At this latter locality, the Obolus sandstone, with conglomerate, fills hollows and cracks in the Lower Cambrian sandstone.

The dark shale at the top of the formation is thicker at Packerort than in any other section, and, as has been noted already by Schmidt, it thins to the eastward, until it is entirely absent at Narwa. Still further east it comes in again and is seen far eastward, being four and one half feet thick at Papowka and one foot on the Lawa at Wassilkowa. Bassler cites the variable thickness of the Dictyonema shale as evidence of erosion before the time of deposition of the overlying "Glauconite sandstone." The evidence on this point does not seem entirely clear, and the presence at Narwa of only four inches of "Glauconite sand" at the point where all the shale is missing does not favor that interpretation, as one would expect the greatest amount of sand in the deepest erosion hollows. Moreover, the glauconite sand is thickest where the shale is thickest, and suggests the alternative explanation, partly borne out by its fauna, that the "Glauconite sandstone" may really belong to the Packerort formation, representing the deposits of the third and emergent phase of the cycle. It should be noted that the Dictyonema shale is usually unfossiliferous, fossils being common only along the western portion of its outcrop, the most western locality being on the island Odensholm where they are found in loose pieces cast up on the shore and the most eastern so far reported being on the Isenhof stream between Asserien and Ontika.[1]

[1] Eichwald (17), however, reports Dictyonema from as far east as Zarskoe Selo, south of Petrograd, and also at Narwa, where there is no Dictyonema shale. According to Schmidt (47), Dictyonemas have been found in lenses of limestone at the latter locality, and this was probably the source of the ones reported by Eichwald. This of course suggests that the Glauconite sand at Narwa may not be a representative of the real Glauconite sand as developed at other localities, but a residium from the Dictyonema shale. Lamansky (29, p. 197) states that graptolites have also been found in the Lower Linsenschicht at Narwa, and that they were sent to Dr. Holm for study, but I have found nothing more in the literature about them. Lamansky thought that they would prove to be the same as those found by Holm in Oeland (Tetragraptus fauna).

At Packerort the most fossiliferous layers are in the upper part of the shale, and it might be inferred from this that in the eastern region the upper layers had been removed by erosion, but it is equally possible that they were never deposited there.

The characteristic fossils of the Packerort formation are the various species of Obolus, chiefly *O. apollinis*, in the sandstone, and *Dictyonema flabelliforme* in the shale. Species of other genera of inarticulate brachiopods are found in the sandstone, and the shale has furnished several species of graptolites which have not yet been satisfactorily identified. If Schmidt's (44, p. 16) figures are to be trusted there may be a Didymograptus in this fauna.

The Obolus or Unguliten sandstone, has, like the Lower Cambrian clay of the same region, often been cited as an example of a formation which has never been consolidated. At nearly all exposures it is a friable sandstone which crumbles readily under the hammer, but in certain places it has considerable hardness, and one receives the impression that the present condition is due to the removal of the cement through leaching. The surface water enters the sandstone through joints in the overlying limestone, and being checked in its further downward passage by the Cambrian clays, naturally moves through the sandy beds.

Walchow formation. B_{I} and B_{II} (Glauconitsand and the Glauconitkalk) of Schmidt; B_{I}, $B_{II\alpha}$, $B_{II\beta}$, $B_{II\gamma}$ and $B_{III\alpha}$ of Lamansky.

While the Packerort formation is best developed at the extreme western end of the Ordovician outcrop, the succeeding formation finds its best expression in the east. This, however, is not due to the fact that the Walchow formation was deposited in a sea invading from the east, for the opposite seems to be the case, but because the upper layers have been eroded away at the west, as has already been shown by Lamansky (29). The lower members of the formation, the "Glauconitsand" and the "Glauconitkalk" are better developed in the west than in the east, and the deposits of the same age as the Glauconitkalk are still thicker in Sweden.

On the Walchow and on the Lawa at Wassilkowa this formation has five bands easily distinguished on lithological grounds, each with its own faunal characteristics. The measurements given here are those of the section on the Lawa which presents a more satisfactory natural section than any seen on the Walchow. (Plate **4**).

The lowest bed is a soft, easily disintegrated green sandstone, six feet in thickness. Upon it rests two or three layers of limestone, making a total thickness of six feet, which usually form a bold projection from the cliff, being preceded and followed by softer strata.

These layers are often vividly colored, being generally red or purple with patches and spots of green and yellow, and usually contain quantities of rather large green grains of glauconite. The characteristic fossil is *Megalaspis planilimbata.* Above these layers comes a band, thirteen feet in thickness, of thin-bedded, shaly limestone and shale in which *Asaphus bröggeri* and *Onchometopus volborthi* are found. These strata weather to a soft gray mass, and above them are harder layers of limestone with less shale, making the fourth division, eleven feet in thickness. This also is a blue-gray limestone, and contains *Asaphus lepidurus* and *Megalaspis gibba* in numbers. At the top of the formation is another thinner-bedded, softer, gray and green limestone, characterized by a great abundance of *Asaphus expansus*, and containing also *A. lamanskii*, and *Nileus armadillo*, this limestone being about ten feet thick. This makes the total thickness of the formation on the Walchow and Lawa about forty-six feet.

When followed westward this formation becomes thinner and usually at the expense of the upper members, though the green sand may thin to practical disappearance. Thus, on the Papowka, the green sand is only one foot thick, the *Megalaspis planilimbata* or lowest limestone bed is seven feet thick, and is followed by twelve feet of shaly limestone, the greater portion of which contains the *Onchometopus volborthi* fauna, while at the top, *Asaphus lepidurus* and *Megalaspis gibba* are found. The layers with *Asaphus expansus* are gone entirely. Further west, the shale almost entirely disappears from this part of the section, though there is usually a thin shaly layer or a shaly parting. The limestone of the section becomes very thin, but the three faunas, *M. planilimbata*, *Onchometopus volborthi*, and *Asaphus lepidurus*, persist as far west as Reval, though further west the *Asaphus lepidurus* fauna is lost, and of the zone with *Asaphus bröggeri* and *Onchometopus volborthi* only a thin remnant remains in the section at Packerort. At this latter locality the green sand has the greatest thickness known, eleven feet, followed by two and a half feet of hard green limestone with large grains of glauconite and many trilobites, among them *Megalaspis planilimbata*, then one foot three inches of thin-bedded limestone and shale, this containing *Asaphus bröggeri*. The limestone of the formation is therefore only three feet and nine inches in thickness, the two younger faunas are absent entirely, and the strata containing the others are very thin. Besides the absence of the younger faunas there is other evidence which indicates that erosion has taken place since the deposition of the upper strata of this formation. In the section at Packerort, the thin-bedded limestone is followed by a conglomerate in which there are large numbers of pebbles

of green and gray limestone and pieces of shale; and at Catherine Park, Reval, the green "Glauconitkalk" is likewise followed by a six inch layer of conglomerate in which there are pebbles of limestone full of glauconite. This unconformity is not newly discovered, but was distinctly foreshadowed in Schmidt's papers, and was definitely worked out by Lamansky, who, however, placed the layers containing *Asaphus expansus* in the overlying formation instead of with the older strata, as the evidence seems to require. (Plate **2**).

The doubtful member of this formation is the green sand. It is placed here, because there is an undoubted break in the sedimentary record between the Dictyonema shale and the *M. planilimbata* limestone. In Norway and Sweden one finds between these two formations the Ceratopyge limestone, with a fauna which, though it occupies no great thickness of strata in Scandinavia, really endured for a very long period of time. During this interval no deposition was taking place in the region in Russia here discussed, and, apparently, neither was there any great erosion, the district standing nearly at sea-level. During some part of this time the green sand seems to have accumulated, perhaps as a beach sand, at least at first, but probably reworked as a whole or in part by the invasion of the sea in which were deposited the Walchow sediments. It differs from an ordinary beach sand not only in its green color, but in the presence of much fine clay. It usually shows neither stratification nor cross-bedding. The fauna is a scanty one. In the west, on the Baltishport peninsula and near Reval, a few specimens of *Obolus lingulaeformis* Mickwitz, a Lingula, a Siphonotreta and conodonts have been found. At Papowka, Lamansky has referred to the "Glaukonitsand" a sandy part of the limestone, and has obtained from it a considerable fauna which he considers to be distinct from the regular *M. planilimbata* fauna and allied to the Ceratopyge fauna of Scandinavia. This fauna is however, too closely allied to the *M. planilimbata* fauna to indicate the presence of either a Ceratopyge or Lower Didymograptus fauna, and the strata containing it would seem to go naturally with the limestone rather than with the sandstone of the section.

So far as I have seen it, the fauna of the green sand seems to be allied with that of the Ungulite sandstone below, rather than with the limestone above. The sand and clay content of the bed may easily have been derived from the denudation of the underlying Packerort formation, which was undoubtedly uplifted and subjected to erosion at some localities, even though we can not now point definitely to the particular places, and, such being the case, it seems more probable that the sand belongs to the later and not the earlier sedimentation.

In the east, on the Lawa, Walchow, and other rivers of that district, the limestone of the Walchow formation is rather soft, and disintegrates very readily on exposure, so that great numbers of very beautifully preserved fossils may be obtained, especially in the extensive quarries on both sides of the Walchow above Old Ladoga.

The lowest limestone has a decidedly green color, due to the presence of a considerable quantity of glauconite. The glauconite is in small grains about .5 mm. in diameter, and makes a considerable part of the limestone. In Esthonia the corresponding bed is much harder, is a deeper green in color and contains more and larger grains of glauconite, up to 2 mm. in diameter.

All of the limestone in the formation on examination in thin section proves to be made up almost entirely of fragments of fossils, largely trilobites, but also ostracods, bryozoans, and brachiopods. All these are in small pieces, sometimes 2 mm. long, but generally much less. The cement consists of exceedingly small grains of crystalline calcite. Stray grains of glauconite are seen in most of the slides from all horizons in the formation. The red and brown colors of some of the limestone prove to be due to a stain and grains of limonite surrounding the crystals of the matrix and filling the zoecia of the bryozoans. The limonite halo around the grains of glauconite suggest that the source of the iron compound may possibly be found in the decomposition of that mineral. (Plate 5).

In a slide from Putilowa especially, very few of the glauconite grains are unaltered, but almost all show a border of limonite, and the grains contain much of a dark alteration product along cracks.

The glauconite from the glauconite sand and limestone has been analyzed by Kupffer (27), some of whose analyses are quoted below.

	1	2	3	4
SiO_2	51.93	51.24	50.91	52.38
Al_2O_3	9.20	12.22	9.81	10.53
Fe_2O_3	15.31	13.44	16.54	13.77
FeO	4.73	3.06	4.80	4.36
MgO	3.79	3.93	3.62	4.96
CaO	.30	.10	.30	.08
KO	8.02	7.50	8.09	8.00
NaO	.20	.31	.14	.04
HO	5.52	8.20	6.48	5.88
Quartz	.40			
	99.40	100.00	100.69	100.00

The analysis given in column 1 was from the glauconite sand at Karya-Oro near Ontika, Esthonia, and 2 from the glauconite limestone at the same place; 3 was from the glauconite limestone, and 4 from the glauconite sand, at Baltishport.

For comparison, one may quote the following, the first two from Clarke's Data of geochemistry, p. 494, and the other three from an abstract of a paper by Glinka. (Zeitschr. kryst. u. min., 1898, **30**, p. 390).

	1	2	3	4	5
SiO_2	51.56	53.61	48.95	49.53	52.96
Al_2O_3	6.62	9.56	7.66	5.84	12.76
Fe_2O_3	15.16	21.46	23.43	20.06	13.56
FeO	8.33	1.58	1.32	5.95	2.34
MgO	.95	2.87	2.97	2.92	4.11
CaO	.62	1.39	.57	.56	....
Na_2O	1.84	.42	.98	.46	.47
H_2O	10.32	5.96	4.93	4.91	4.91
K_2O	4.15	3.49	9.54	9.31	8.69
MnO	.....	trace	....	....	....
	99.55	100.34	100.35	99.54	99.80

The glauconite in column 1 is from a greensand marl, Hanover Co., Virginia; 2 is the mean of four analyses of deep-sea deposits from the Challenger Report; 3 is a glauconite from the Cretaceous sandstone at Padi, Government of Saratow, Russia; 4 is from an Eocene sandstone in the Urals; 5 from the Glauconite limestone at Udriass, Esthonia.

It will be noted that the Russian Ordovician glauconite contains less iron, more alumina, much more magnesia, and more potash than the other glauconites listed.

Kunda formation. B_{III} (Vaginatenkalk) of Schmidt; $B_{III\beta}$ and $B_{III\gamma}$ of Lamansky.

This well-known formation may be seen throughout the whole extent of the Ordovician from the Sjass to the Island Rogo, off Baltishport, but is best exposed in Esthonia. I have selected Kunda as the type-section because it is there well exposed and richly fossiliferous. A drain recently dug by the Cement Company at the extensive quarries about three miles south of Port Kunda on their private railroad exhibits a complete section of the formation, which is here fifteen feet thick. A large quarry, opened during the summer of 1914 will,

if completed as planned, also furnish a complete section through the limestone. This formation is quite thick in the eastern exposure on the Walchow but is very poorly exposed, only the basal portion being cut by the extensive quarries, and the greater part being seen only at places along the river bank just below Dubowiki.

At the base of the formation one finds the so-called "Lower Linsenschicht," a rather soft clayey limestone six to twelve inches in thickness, full of small flattened grains of about the size, shape, and color of small Leperditias, with which Schmidt first confused them. These small "lentils" have a concretionary form and have been shown on chemical analysis by Kupffer (27), to consist of clay containing iron oxides and calcium phosphate.

The layer containing these linsen does not seem to have been formed under abnormal chemical conditions, for it is fossiliferous, often highly so, being in fact noted as the best stratum for *Pliomera fischeri* and *Lycophoria nucella*, and the fossils are of full size and show no abnormalities. It is probable that the "Linsenschicht" really represents a basal conglomerate for the Vaginatenkalk, for in places, as at Reval and Packerort, there is a real conglomerate which replaces the "Lower Linsenschicht."

East from Reval this conglomerate was not seen, and west from that city there is no "Lower Linsenschicht," but both the conglomerate and the "Lower Linsenschicht" represent the basal bed of the formation.

The "linsen" of the Linsenschicht are almost opaque in the thinnest sections which can be obtained of these soft rocks, but show a definite concentric structure.

An analysis of some of them from Ontika by Kupffer is as follows:

SiO_2	5.93
Al_2O_3	3.95
Fe_2O_3	69.92
Mn_2O_3	.26
MgO	1.21
CaO	.46
P_2O_5	1.99
HO	12.42
Organic	.68
Residue	3.09
	99.91

This analysis may be compared with those of the oölitic hematite ore of the Clinton of New York, listed by Newland and Hartnagel (Bull. 123, N. Y. state mus., 1908, p. 62).

	1	2	3	4	5
Fe_2O_3	69.17	42.97	79.98	63.00	71.82
SiO_2	11.57	29.72	9.98	12.63	11.34
Al_2O_3	3.92	4.13	2.4	5.45	3.91
MnO	.19	.37	tr.	.15	1.63
CaO	5.8	8.57	1.54	6.2	3.97
MgO	2.27	1.96	.3	2.77	2.21
S	.28	.837		.23	
P_2O_5	1.726	1.534	1.239	1.5	2.096

Comparing these analyses, it will be noted that the "linsen" have about the same iron content as some of the Clinton oölites, and about the same amount of clay, manganese, and phosphates, but less silica, lime, and magnesia. The high silica content of the Clinton ore is due to the presence of nuclei of sand in the spherules, whereas the nuclei of the linsen, when such can be observed at all, seem to be calcitic fragments of fossils.

The linsen have much the same size and shape as the spherules in the oölitic Clinton ore, most of them being from .5 to 1 mm. in diameter, and somewhat flattened or lentil shaped. This flattening, in the case of the Clinton oölites, has been ascribed to pressure, but in the case of the linsen it seems to be the original form, for, while these discs often lie parallel to the bedding, very large numbers of them do not, but are imbedded at all angles.

The mode of occurrence of these linsen has some bearing upon the rival theories of the origin of the oölitic sedimentary hematite ores. The view put forward by Shaler was that they were replacements of original limestone effected by the circulation of ground water, while C. H. Smyth, Jr., considers these ores to be original sedimentary deposits. The Russian occurrences are explainable only by Professor Smyth's views, since: —

First; the linsen occur in a limestone which is not otherwise oölitic.

Second; the linsen occupy definite layers which can be traced laterally some 300 miles through a series of gentle undulations, always maintaining a definite horizon, as shown by evidence of fossils, and without any relation to the present water table.

Third; the lower linsenschicht passes laterally into a true conglomer-

ate showing that it was formed at or near the shore, and at a time immediately subsequent to a period of erosion.

The Kunda formation has a somewhat irregular thickness, being thickest in the east and very thin at the west. On the Walchow it is thirty-two feet according to Lamansky, at Papowka it is thirty-four feet with the top not seen, at Ontika eighteen and one half feet, at Asserien fourteen and two thirds feet, at Kunda fifteen feet, at Reval four feet, and three and one half feet at Packerort. The abundant fauna at Reval is practically the same as that at Kunda, but as the fauna seemed to be the same all through the section at Kunda, this in itself would not indicate whether the thinness at Reval was due to erosion at the top of the formation or to a smaller original deposition.

Schmidt states that west of Reval the Orthoceras limestone passes into a sandstone, but I myself saw no evidence of this, either at Baltishport or on the Island Rogo. At these localities the formation consists of a rather thick-bedded hard limestone without many fossils, and at the base is a conglomerate made up of pebbles of green glauconitic limestone and irregular pieces of dark shale, these latter proving on analysis by Kupffer to contain, in some cases, a large percentage of phosphoric acid.

The fauna of the Kunda formation is dominated by Mollusca, mostly cephalopods and gastropods. Pelecypods are rare, making here their first appearance in the Russian section. Typical fossils are *Vaginoceras vaginatum*, *V. commune*, *Maclurites helix*, *Estonioceras lamellosum*, *Asaphus raniceps*, *Pliomera fischeri*, *Lycophoria nucella*, and *Pterygometopus sclerops*.

WIERLAND GROUP. C1, 2 and 3, and part of D_1 (Echinosphaerites limestone, Kuckers schicht, Itfer schicht, and basal portion of the Jewe schicht), of Schmidt.

As already noted, Schmidt gave geographic names to all the strata above the "Glint," but these names are of very unequal value, some of them designating true formations, and others indicating merely the quarry at which a certain fauna or type of strata was seen. The faunas of all three of the formations named above are very closely knit together by the presence of *Echinosphaerites aurantium* and species of Chasmops. The name Wierland which I have applied to the group is that of the district in which most of the localities for Kuckers and Itfer are located, and in which the lower divisions are well developed. The lower members are also given geographic names to correspond to the two upper members named by Schmidt. There is really a greater faunal change between the Reval and Dubowiki members than between any other two in the group.

Dubowiki formation. C_α (Upper Linsenschicht and lower part of the Echinosphaerites limestone), of Schmidt.

This formation, like the Kunda limestone is best exposed at the east, where it reaches its best development on the Walchow River at St. Michael Archangel, opposite Dubowiki, just above the steamer landing and below the railroad bridge. At this locality the base of the formation is not seen, but fourteen feet of soft calcareous mudstone are exposed, the base twenty-three and one half feet above water level in the river. This outcrop is capped by twelve feet of the harder dolomitic limestone of the Reval formation. Schmidt and Lamansky state that the upper part of B_{III} (the Kunda formation) is to be seen in the basal parts of the quarries at St. Michael Archangel, but I was not able to find it, and so did not see the contact between the two formations here. The upper part of the Kunda is, however, exposed along the river bank about a mile below the steamboat landing and with the prevailing low dip should still be above the water-level at St. Michael Archangel. The thickness of the Dubowiki at this locality is therefore uncertain. It can not be more than thirty-seven feet or less than fourteen feet in thickness, and is probably twenty-five to thirty feet, as Dubowiki fossils, which seemed to be in place, were found within ten feet of the water's edge.

Schmidt and Lamansky agree that there is no "Linsenschicht" at the boundary between B_{III} and C_1, at this locality. Following the Dubowiki westward it is present at various sections, but always thinner than at the typical locality. It is well exposed in the cement quarry and on the railroad south of Asserien, where it is fifteen and one half feet in thickness. It is here a hard compact limestone, unlike the soft marly beds at Dubowiki; and at this locality, as well as at Ontika and all the other localities in Esthonia the "Upper Linsenschicht" is present at the base of the formation. This linsenschicht is not a definite, rather thin band, like the Lower Linsenschicht, but the linsen are smaller, less abundant, and scattered through a thickness of six or seven feet. Continuing westward, the Dubowiki formation thins out entirely, so that at Reval the upper Linsenschicht is reduced to a thickness of one foot and at Baltishport to ten inches, and it is at the base of the Reval formation instead of the Dubowiki. The Upper Linsenschicht is therefore a tangential formation and represents the invading base of the Wierland group.

The fauna of the Dubowiki retains some survivors of previous faunas, though very few species are common to this formation and those below. This formation is particularly marked by the intro-

duction of Echinosphaerites and Chasmops, and the acme of the variation of the genus Asaphus. Echinosphaerites is not found in the Linsenschicht at the base of the formation, though it does occur with linsen a few feet above the base at some localities (Ontika and Asserien).

The soft limestone from St. Michael Archangel, on the Walchow, weathers to a nearly white flour which, when wet, forms a very sticky mud. A thin section shows that this rock is made up almost entirely of very small fragments of fossils, few of which reach 1 mm. in length and none have more than one fourth that thickness. The most abundant fragments are of some organism with minute tubules, possibly a Solenopora. Bryozoa, Ostracoda, and trilobites seem to furnish a large part of the material. The fragments are much more finely comminuted than in the limestone of the Walchow.

Characteristic fossils are: — *Echinosphaerites aurantium, Clitambonites adscendens, Porambonites aequirostris, Chasmops nasuta, Ceraurus exsul, Illaenus tauricornis, Asaphus cornutus,* and *A. kowalewski.*

Reval formation. $C_{1\beta}$ (upper part of Echinosphaerites limestone) of Schmidt.

Resting upon the Dubowiki at Dubowiki on the Walchow, and through the greater part of Esthonia, and upon the Upper Linsenschicht from Reval westward, is a hard, compact, sparingly fossiliferous limestone, frequently magnesian in character, to which the name Reval may be applied, as it is very extensively quarried at that locality. The thickness and lithological character of this formation are remarkably uniform all the way from Baltishport to Dubowiki and it is a favorite quarry rock wherever accessible. The beds vary in thickness from an inch to about a foot and afford both building and flagging stone. It is extensively used for both purposes in Reval, Narwa, and Petrograd. Certain of the layers are traversed by vertical tubes suggesting worm-burrows. The thickness varies from twenty-five to thirty-five feet. Fossils are not very common, and in many cases dolomitization has gone on to such a degree that the rock has a porous appearance and the fossils are represented by hollow molds.

The rock has about the same color and appearance as the Galena of Minnesota, and there does not seem to be much question but that the dolomitization has here taken place in beds originally composed mostly of limestone. In thin section the rock from Dubowiki shows irregularly intergrown areas of very small crystals of calcite with irregular boundaries, and areas in which the crystals are of dolomite, about twice the size of those in the areas of calcite, and with definite

crystal form. This rock is not made up of fragments of fossils, like that of the calcareous formations below.

The leading fossil of this formation is *Christiania oblonga* (Pander). Some large cephalopods are found, and in the Government of Petrograd, *Cryptocrinites laevis* (Pander) is a characteristic fossil, and *Echinosphaerites aurantium* (Gyllenhahl) is occasionally found.

The Reval is the youngest formation which appears in the "Glint."

Kuckers formation. C_2, (Kuckerssche schicht or Brandschiefer) of Schmidt.

The Kuckers formation takes its name from the estate of Baron Toll, about five miles northeast of the railroad station Jewe; but the strata are very little exposed at that locality and collecting is now very poor. The same strata are reported by Schmidt to be exposed in a few natural sections along streams but the places were difficult of access and we saw the Kuckers only at the typical locality and at Reval. The formation occupies the low, level land at the top of the escarpment which faces the Gulf of Finland, and the numerous beautiful fossils which it has produced have come from ditches dug to drain this sort of land.

The base of this formation can be seen in the extensive quarries at Reval where the upper three or four feet are a bluish gray calcareous shale and thin-bedded shaly limestone containing numerous cystids, including *Echinosphaerites aurantium*, *Caryocystites balticus*, and *C. aranea*.

In the trench at Kuckers the strata consist of gray and reddish earthy limestone and soft reddish shale known from its combustibility as the "Brandshiefer." Schmidt has listed localities in this formation all the way from the village of Djatlizy south of Gostilizy and west of Petrograd to the point where it goes beneath the waters of the Gulf of Finland southwest of Baltishport. Its large fauna is rather easily recognized. *Chasmops odini*, *Ceraurus spinulosus*, *Porambonites teretior*, *Plectambonites sericeus*, *Oxoplecia dorsata*, *Echinosphaerites aurantium*, and *Platystrophia lynx* were the more common species seen by the writer. Of these, the *Oxoplecia dorsata* is most valuable as a cosmopolitan form, but, in Russia, confined apparently, to this horizon.

Schmidt estimated the thickness of the Kuckers at from thirty to fifty feet.

Itfer formation. C_3 (Itfersche schicht) of Schmidt.

This member is named from an exposure on the estate of Baron Wrangel at Itfer, northeast of Wesenberg. This exposure, a small quarry, is now completely overgrown and nothing is to be seen. I

was able to find the formation in another small, shallow, old quarry at Wannamois, and in a small ditch at Tolks. The strata here consist of thin-bedded (layers two to four inches thick) gray and almost white limestone, rough to the touch, full of silica, and with silicified fossils. The fossils included *Echinosphaerites aurantium*, which species we also found in the lower layers of strata assigned to the next formation, the Jewe, at the quarry south of the Guthof at Kuckers, and at Aluver, north of Wesenberg. As this species does not occur in the typical Jewe, I propose to extend the Itfer to include all the strata at the above localities which contain Echinosphaerites. These strata lack the shale of the Kuckers member and are lithologically unlike the Jewe, as they weather to a grayish white instead of a rusty yellow.

The geographical distribution of the Itfer is unknown. It is difficult to trace, as it has few fossils peculiar to it, and no very distinctive lithological characteristics. It has not been identified outside the vicinity of the typical locality, but Baron Toll called our attention to an outcrop of strata on his estate which were stratigraphically a few feet above the typical Kuckers in the "Graben," and which may prove to be Itfer. They consisted of a thin-bedded soft, earthy, gray limestone, and contained too few fossils to permit of positive identification of age.

Schmidt estimated the thickness of the Itfer at twenty to thirty feet.

Jewe formation. D_1 (Jewesche schicht, except for the basal portion), of Schmidt, but not including the Kegel and Wassalem.

The Jewe is a formation with distinct lithological characteristics, contains a well-marked and easily recognized fauna, and is well exposed along a line extending from Gatschina in the Government of Petrograd to the coast near Spitham in the northwestern corner of Esthonia.

At the type-locality, Jewe, in an abandoned quarry south of the railroad there is an exposure of about twelve feet of light gray to yellow magnesian limestone of earthy texture. Some layers are more shaly than others and weathering brings this out strongly. Still higher strata of the same formation are to be seen a mile to the southwest on the Gut Eichenheim, where, in similar strata, fossils are somewhat more plentiful.

A much better exposure of the Jewe is that at Aluver on the railroad to Kunda, three miles northeast of Wesenberg. Here about twenty-five feet of the Jewe are shown in a quarry, with the upper part of the Itfer, full of Echinosphaerites, exposed at the lower part. The rock is a fairly compact bluish limestone with earthy texture; on

weathering it becomes a mass of rusty yellow fragments. Fossils are very plentiful in the upper part of the quarry. The Jewe covers a large area north of Wesenberg and small quarries and ditches furnish many exposures. I saw the Jewe further west beyond Nemme, about seven miles southwest of Reval and at St. Mathias, five miles south of Baltishport. At both these localities the fossils and lithology were the same as at Jewe itself and the formation is throughout its extent a very distinctive one. The most common and characteristic fossils are: — *Platystrophia lynx* (very robust variety), *Clitambonites schmidti*, *Hemicosmites extraneus*, and *Poramborites ventricosus*. Equally characteristic are the peculiar conical bodies figured by Schmidt (44, p. 331). These appear to be of organic origin, but their exact nature is not known.

Kegel formation. D_2 and D_3 (the Kegel, Wassalem and, west of Reval, the "Wesenberg") of Schmidt.

At the typical locality, at Kegel, southwest of Reval, about eight feet of strata are exposed in two quarries about one and one half miles west of the station. The strata here are limestone without shale, in layers two to six inches thick. When fresh the limestone is blue and fine grained, but weathers to a yellow shaly mass. The fossils weather more rapidly than the matrix and the rock is left full of holes. The most abundant fossil is *Cyclocrinites spasskii*, which occurs in immense numbers. *Clitambonites anomalus* and *Asaphus kegelensis* are also quite common. The country south of Kegel is very flat and the rock everywhere near the surface. Following the railroad or highway southwest from Kegel station, the Kegel beds with their characteristic fossils are seen in ditches and shallow quarries till one comes to a broad low ridge which is made up of a very different rock, to which the name Wassalem has been given. At the large quarries in Wassalem, the strata are light gray to white, very coarse-grained massive limestone, the lower ten feet with feebly developed partings, the upper three feet very irregularly bedded and containing some shaly lenses. The lower part is quarried in large blocks, up to three feet in thickness, for use as a marble. In this portion there are few fossils, other than joints of the columns and plates of Hemicosmites. Weathered pieces show that the rock is practically made up of these. The upper three feet contain lenticular and cross-bedded strata and lenses of fine-grained buff limestone with numerous specimens of Illaenus. Fossils may be found in this upper portion, especially in pockets where the limestone has decomposed, leaving a mass of yellow, calcareous earth. The most common fossils are bryozoans and Hemicosmites. The

Wassalem thus shows at its type locality many of the characteristics of a reef. The outcrop of the Wassalem has a width of about two miles and south of it one finds blue and buff, very fine-grained dense limestone, somewhat purer than that at Kegel, but with the same fossils, *Cyclocrinites spasskii* (or *C. roemeri*, as Stolley calls it) being very abundant. This limestone appears to belong to the Kegel, though it has previously been called Wesenberg. The reasons for this belief are given on page 202. The Bryozoa described by Bassler as coming from the Wassalem were very probably derived from a lense of the fine-grained buff limestone associated with the reef, for their appearance and the lithology of their matrix is entirely unlike that of the typical Wassalem. (Plate 6).

Wesenberg formation. E (Wesenberger schicht, *partim*), of Schmidt.

The strata of this formation are well shown in three or four shallow quarries about one and one half miles southeast of the town from which it derives its name. The limestone is a very fine-grained, dense, blue to yellowish buff rock, so fine grained as to have received the name of "lithographic stone." It is usually in layers three to five inches in thickness, the layers separated by thin shaly partings. The good fossils adhere to the limestone and stand out in relief when the shale is washed away. The deepest quarry shows a face of sixteen feet, the lower eight feet being compact light blue limestone and the upper eight feet somewhat less compact and more magnesian limestone which becomes yellowish on weathering. Lithologically these strata differ from the rocks of the Kegel at Kegel in being less earthy, more compact, and in containing definite partings of shale. Fossils are exceedingly abundant in these quarries, the most conspicuously common being *Amphilichas holmi*, *Homolichas eichwaldi*, *Chasmops wesenbergensis*, and *Encrinurus seebachi*.

The Baltic railroad runs in a southwesterly direction from Wesenberg to Taps and thus traverses the outcrop of the Wesenberg diagonally. Between the two stations there are several small cuttings, one of them, about two miles east of Taps, being in strata very near the top of the formation. A tiny quarry, a few rods south of the railroad and near the stream just east of Taps shows strata even higher in the formation. In both localities the rock is a hard fine-grained yellowish to buff limestone, without shale, and fossils were exceedingly scarce. In the small quarry I obtained *Clitambonites wesenbergensis*, a *Discoceras*, and *Chasmops wesenbergensis*, fossils which are characteristic of the Wesenberg at the type-locality. A half mile south of these outcrops one finds the Lyckholm, with typical fauna.

The Wesenberg was believed by Schmidt to be a thin formation, the thickness being estimated by him at not more than thirty feet. From the width of the outcrop in the vicinity of Wesenberg, one would expect a somewhat greater thickness.

Distribution of the Kegel and Wesenberg formations.

According to Schmidt the outcrops of the Kegel and Wesenberg strata form parallel bands extending from the western part of the Government of Petrograd to the western border of Esthonia. In the eastern part of this belt the Wesenberg is said to overlie the Kegel proper, while in the western area the Wassalem intervenes between the Kegel and Wesenberg. I regret to say that I have not been able to trace these formations in the field as I should like to, but from what I have seen in the course of traverses in the neighborhood of Wesenberg and Taps, and between Baltishport and Hapsal, and the débris on the northern end of the Island of Dago, I very much doubt whether these formations do outcrop as parallel belts. The distribution of the Kegel is given by Schmidt in detail, as follows: — The most easterly outcrop is at Poll (a short distance east of Wesenberg) where the Kegel is said to outcrop in the ravine and the Wesenberg on the bank above; then north of Wesenberg, at New Sommerhusen, west of Taps on the railroad between Kedder and Rasiek, at Penningby, Nappel, Jelgimäggi (south of Reval) Friedrichshof, Kegel, Habbinem, and Kreuz.

I did not see the locality at Poll, but visited the old quarry at New Sommerhusen, where the lithology and fossils are both typical of the Jewe, and not at all Kegel. The locality "north of Wesenberg" is probably an outcrop on the road to Haljal, and about three miles north of Wesenberg. Here, where the road mounts a slight terrace, is an exposure of nine feet of bluish and yellowish compact limestone containing many fossils, among which were *Amphilichas holmi* and the large Porambonites so common in the quarries at Wesenberg, and which are believed to be characteristic of that formation. If the strike here is approximately east and west, as it is supposed to be, and as it actually is in most places, then the strata at this locality must be but a short distance above the top of the Jewe, which outcrops at Aluver and New Sommerhusen at approximately the same level. In a ditch at Welch, about five miles northwest of this outcrop, I obtained, through Herr von Dane, some specimens whose

matrix reminded me of the Kegel, but which were not diagnostic species. North of Welch there are numerous outcrops of the Jewe. If the Kegel be indeed present in the neighborhood of Wesenberg, it is either very thin or else does not carry the fauna of the Kegel at Kegel.

The next locality mentioned by Schmidt, that between Kedder and Rasick, is forty miles west of Wesenberg, and less than thirty miles east of Kegel. I did not visit this locality myself and am unable to find any adequate faunal lists for it or for any of the other localities mentioned between it and Kegel. Owing to its proximity to the latter place, however, it is very probable that one finds here a real Kegel fauna.

Schmidt gives the following localities from east to west, for the Wesenberg: — from Polja, on the River Pljussa in the western part of the Government of Petrograd, then at Paggar, Pülse on the stream Isenhof, at Poll, Raggafer, Wesenberg and other outcrops on the railroad in that vicinity, at Körweküll north of Taps, at Wait south and a little east of Reval, then southwest of Reval at Forby, Munnalas and Paeküil, and as boulders on the Islands Oesel and Dago. Of these localities I have seen only Wesenberg and the localities on the railroad as far as Taps, and the loose boulders on Dago, but have also seen material from Munnalas. The fossils listed by Schmidt from Polja, Paggar, Püllsse, Poll, Raggafer, and Körweküll leave no doubt that these eastern localities belong to the Wesenberg. When one inspects the lists, usually very meager, from the more western localities, beginning with Wait, one finds however, a marked change. In these localities the common, and usually the only fossil, is *Cyclocrinites spasskii*, a typical Kegel fossil, but one so rare at Wesenberg that I was unable to find it, though Schmidt has listed it from that locality.

On the shore at Kertel, on the northern side of the Island Dago, numerous angular blocks of limestone are found which are not seen in place, but which are evidently derived from a ledge not far below water-level. The blocks contain great numbers of *Cyclocrinites spasskii* and lesser numbers of other typical Kegel fossils. At the new factory at Hohenholm, west of Kertel, this same limestone was seen in a trench immediately in contact with the Lyckholm.

The fauna of the Kegel has never been carefully listed, the best enumeration being that given by Schmidt (44, p. 34). This one is, however, subject to considerable revision, and contains fossils found in both the Jewe and the Wesenberg. In both the Kegel and Wesenberg the trilobites are most important, because best known, and a study of their distribution throws considerable light on the present subject.

Of nine trilobites which are supposed to be restricted to the Wesen-

berg, four are found at Wesenberg only, one only at Wesenberg and Raggafer, and four are found in the western as well as the eastern localities. These are *Homolichas eichwaldi* and *Isotelus remigerum*, which occur at Forby as well as at the eastern localities, *Chasmops wesenbergensis* which is found at Wait and Forby, and loose on Dago, and *Pterygometopus nieszkowskii*, found at Wait and Munnalas.

There are eleven species of trilobites reported from the Kegel; six of which are common to the Jewe and Kegel and thus of no importance in this discussion; four, *Pterogometopus kegelensis*, *Chasmops brevispina*, *Basilicus kegelensis*, and *Illaenus linnarssoni*, are found only in the western localities; and a single one *Asaphus lepidus* var. *kegelensis*, is reported from both east and west. This last species has no particular value, for it is very like *Asaphus lepidus jewensis;* and it is reported by Schmidt not only from New Sommerhusen, which we know to be Jewe, but also from localities in the Government of Petrograd east of the limits which Schmidt himself set on the distribution of the Kegel. Of the six trilobites found in both the Kegel and Jewe, five are found in the Kegel in the typical region, while one, *Chasmops mutica*, is listed as a Kegel species only from its occurrence at New Sommerhusen. That there should be five species common to the lithologically unlike Jewe and Kegel, and no species common to the lithologically alike Kegel and Wesenberg strikes one as strange.

The results of the study are rather suggestive. Subtracting the one species reported from the "Kegel" at New Sommerhusen, there are nineteen species of trilobites reported from the Kegel and Wesenberg. Of these no one is reported as common to the two, while six of the species in the Kegel occur in the Jewe below. Of the four which may be considered strictly typical of the Kegel, not one is found at any locality of the Kegel east of the locality on the railroad near Kedder, forty miles west of Wesenberg. Of the nine trilobites in the Wesenberg, five are restricted to the typical region about Wesenberg and do not occur in the western region, and four are reported in both eastern and western localities, three of them at Forby, one at Wait, one at Munnalas, and one on Dago.

The most abundant fossil in the Kegel at Kegel itself is *Cyclocrinites spasskii*, using that term in its old, broad sense.[1] Following

[1] This usage is, I believe, fully justifiable. All of the five species described by Stolley (51), from Esthonia were found by him associated in the same blocks, so that, so far as their stratigraphic value is concerned, one specific name is as good as five. Most of Stolley's specimens seem to have come from loose boulders at localities south of the actual outcrop of strata containing these species.

the railroad or highway southwestward from Kegel, one continues to find Cyclocrinites as the common fossil until the coarse-grained, white limestone of the Wassalem is reached. After crossing the outcrop of this formation, the beds above are similar to those below, though with less shale, and still full of the Cyclocrinites.

Cyclocrinites seems to be confined very largely to the district west of the longitude of Reval. It is reported by Schmidt from the Jewe at Jewe and from the Wesenberg. At Jewe I succeeded in finding a few small specimens of *Coelosphaeridium cyclocrinophilum*, and this is probably the fossil which Schmidt had seen. At the quarries at Wesenberg I saw no Cyclocrinites, though I looked for it particularly, especially on my second visit, after I had collected many specimens at Kegel and in the loose blocks on Dago. It is therefore, I think, safe to assert that Cyclocrinites is a very rare fossil, if present at all, at Wesenberg.

Stolley reports no species from the quarries at Wesenberg, though he visited that locality, and also had access to the material collected by Schmidt (in Dorpat). Stolley (51) described or reported five species, *Cyclocrinites balticus*, *C. schmidti*, *C. mickwitzi*, *C. roemeri*, and *C. spasskii*, from Esthonia, all from the region southwest of Reval, and in the strata above the Wassalem.

At the United States National Museum I have seen specimens collected by Professor Schuchert at Wesenberg while in company with Akademiker Schmidt, and which are labeled *Cyclocrinites spasskii*. These specimens are none of them spherical, though some of them might be interpreted as fragments of spheres. Moreover, they do not show the surface structures of Cyclocrinites, and they do show that if they were originally spherical, they were not hollow spheres, but had a structure extending nearly to the center, as in Coelosphaeridium. I, myself, collected many similar specimens, as they are very common at Wesenberg. They are certainly not Cyclocrinites, and probably not Coelosphaeridium, but this identification, which was probably made by Professor Schmidt, explains the listing of Cyclocrinites from Wesenberg.

Summarizing what has been said on the preceding pages, it appears that: —

1st, the fauna of the strata above the Wassalem is more like that of the Kegel than that of the Wesenberg.

2nd, that the typical Wesenberg fauna is not found in the same region as the typical Kegel fauna, but that both the Wesenberg and the Kegel rest upon the Jewe and are followed by the Lyckholm.

The question suggests itself as to whether the Kegel may not be of the same age as the Wesenberg, instead of being older as has been supposed. On the basis of the faunas this must be at once answered in the negative, for there are only one or two of the long ranging species which are common to the Jewe and Wesenberg, while there are quite a number of species, particularly trilobites and brachiopods, common to the Jewe and Kegel.

The presence of a few of the Wesenberg trilobites at localities south of the outcrop of the Wassalem suggests that there may be a thin edge of the Wesenberg in that region, probably overlying the strata with the Cyclocrinites, but I did not have time to search for outcrops which might have shown such relations. It seems more probable, however, that these trilobites are not restricted to the Wesenberg horizon, but are found in the Kegel as well.

It seems very possible therefore, that the Lyckholm rests at the west on the Kegel and further east upon the Wesenberg, and there is undoubtedly an unconformity at the base of the Lyckholm, for there is at most, only a very small fraction of the normal thickness of the Wesenberg present south of Wassalem. The relations of the formations may be as represented on Plate 3.

THE LOWER AND MIDDLE ORDOVICIAN OF SWEDEN.

To make a direct correlation between the various subdivisions of the Ordovician in Russia and North America is impossible, the testimony of the few species common to the two areas being entirely outweighed by the general unlikeness of the faunas. It was a realization of this fact which caused a visit to Sweden and Norway after studying the Russian sections. I visited the rather complete and easily accessible section at Kinnekulle, and other sections in Västergötland at Hunneberg, Ekedalen, and Alleberg near Falköping. In Östergötland I collected at the large quarries at Borghamm and at the old quarry at Västanä, the Husbyfjol of the literature on trilobites, and visited a number of very poor localities in the vicinity of Motala. In Scania I had the very kind guidance and assistance of Professor Dr. J. C. Moberg, without whose help it would have been impossible for me to have understood the very imperfectly exposed sections on the Fågelsång and at Jerrestad. I was not able to visit Oeland on account

of the war, neither did I see Dalecarlia, but Dr. Twenhofel made some collections for me from the district about Rättvik, on Lake Siljan. In Norway, I visited, under the guidance of Dr. Holtedahl, the Ordovician sections in the vicinity of Christiania and, partly with Dr. Holtedahl and partly with Professor Kiaer, some of the exposures of Stage 4 in the Ringrike district.

The description of the Palaeozoic strata of Sweden has been very ably summarized in English by Professor Moberg in his Historical-Stratigraphical Review of the Silurian of Sweden and a briefer summary of certain facts in regard to the lower beds of the Ordovician has been published by Fearnsides (59). I am indebted to these two papers, and to the original sources from which their facts were derived, for the greater part of what is here set forth in regard to the geology of Sweden. The greater part of the Ordovician of Norway is still inadequately known. The account here is derived chiefly from the works of Brögger (93–95), and Holtedahl (97). No account in English of this section, except that in Geikie's Geology, has, so far as I know, appeared.

The strata of Ordovician age in Sweden are found in isolated patches, usually of small area. These patches may be grouped in bands, having a roughly parallel NE–SW alignment.

The northern band, that in Jemtland and Lapland, has the greatest extent, running far north parallel to the mountains on the boundary between Norway and Sweden. These rocks are, however, except in the southern part, largely metamorphosed. The next band to the south of this has its best exposures in Dalecarlia, and there is a very small area in Gästrikland, especially on the little island of Limön near Gäfle. From the evidence of boulders and fossiliferous sand in cracks on the Åland islands, it would appear that this band may once have connected with the Esthonian strata. To the westward the strata of the Christiania district of Norway are in line with these patches.

The next band is in south-central Sweden, and includes the deposits in Nerike, Östergötland, and Västergötland, while the fourth band is at the extreme south and includes Scania and Oeland, while the Silurian of Gotland is in the same line. The strata are best exposed and least disturbed in Västergötland and Oeland. A brief description of the strata at some of the principal sections in each region follows. It is rather interesting to note that most of the principal lakes of Sweden are connected with these limestone patches. Thus we find Lake Storsjön in Jemtland, Siljan in Dalecarlia, Hjälmaren in Nerike, and the largest lakes, Vänern and Vättern in connection with the Palaeozoic deposits of Västergötland and Östergötland.

Jemtland.

The most recent general account of the Ordovician of Jemtland is that given by Wiman (87), to which account must be added certain facts obtained later by Moberg (75), Wiman, and Hadding (60).

The section of Palaeozoic rocks there is given by Wiman as follows:

Pentamerus kalk.
?
Chasmopskalk with Graptolithenschiefer.
Orthocerenkalk.
Underer Graptolithenschiefer.
Ceratopyge kalk?
Alunschiefer { Olenidenschiefer. / Paradoxidenschiefer. }
Quarzit.

The so-called Ceratopyge limestone is conglomeratic at the base, containing fragments of the Olenus shales. Above it is a limestone with much glauconite, and at the top a somewhat pure limestone. This limestone contains some fossils, referred by Moberg definitely to the Ceratopyge fauna but which seem to indicate fully as much affinity with the Planilimbata limestone. Moberg lists, from Tossåsen: — *Orthis christianiae*, *Niobe laeviceps*, and a Cyrtometopus. At Klöfsjö he found *Niobe insignis* and a *Megalaspis* like *M. stenorhachis* Ang. The thickness of this limestone is not stated but one would infer that it was about one meter.

This is succeeded by a green and gray graptolite-bearing shale, which with the limestone below, make a total thickness of fifteen meters. In the shale are lenses and one continuous bed of limestone. The shales have afforded Wiman: —

Pliomera sp.	*Didymograptus filiformis* Tbg.
Megalaspis sp.	*D. hirundo Salter.*
Leptaena sp.	Phyllograptus sp. ind.
Tetragraptus serra.	*Tetragraptus quadribrachiatus.*

In the limestone he found: —

Megalaspis sp.	Ampyx sp.
Niobe laeviceps Dalm.	Orthis sp.

To the writer it would appear that this entire series, including the limestone at the base, belonged to the Phyllograptuschiefer and that we have here Planilimbata limestone and Phyllograptus shales interbedded. If this is the case, then the Dictyonema shales, Obolus sandstone, and the Ceratopyge zones are absent.

The limestone of the section, the Orthocerenkalk, about thirty-seven meters in thickness, is thus subdivided: —

Orthocerenkalk {
- Platyuruskalk.
- Gigaskalk.
- Asaphuskalk.
- Limbatakalk.

Of the Limbatakalk a thickness of only 1.35 meters of dark red limestone was seen, the guide fossil, *Megalaspis limbata* being present.

In the gray Expansuskalk the following typical fossils were obtained, among others: —

Megalaspis heros.	*Lycophoria nucella.*
Asaphus expansus.	*Orthis callactis.*
Ampyx nasutus.	*Orthis calligramma.*

The Gigaskalk is a rather thick-bedded red limestone with *Megalaspis gigas* and grades into the red, coarse-grained Platyuruskalk with the guide fossil, *Asaphus platyurus,* and cephalopods. Above this is a gray limestone, occupying the position of the Chironkalk of other sections, but without fossils.

The Graptolithenschiefer have been investigated fully by Hadding, (60) who found, immediately overlying the unfossiliferous gray limestone, about eight meters of black shale with layers and lenses of dark limestone, the whole characterized by graptolites and trilobites. He has designated this band as the zone of *Climacograptus putillus,* and finds there, among other fossils: —

Didymograptus superstes Lapw.	*Nileus armadillo* Dalman.
Diplograptus perexcavatus Lapw.	*Ogygiocaris dilatata* Brünn.
Climacograptus putillus Hall.	*Trinucleus coscinorrhinus* Ang.
C. scharenbergi Lapw.	*Telephus bicuspis* Ang.
Triarthrus becki humilis Hadding.	*Robergia micropthalma* Linrs.

In slightly higher beds, with less limestone and more shale, he obtained, with others: —

Dicellograptus sextans exilis E. & W.	*Ogygiocaris dilatata* Brünn.
Nemagraptus gracilis remotus E. & W.	*Nileus armadillo* Dalm.

This he designates as the zone of *Nemagraptus gracilis,* and it in turn is followed by similar shales containing *Dicranograptus clingani.* Of the fauna associated with this latter graptolite Hadding gives no list, but the shales containing it are presumably those which Wiman refers to the Chasmopslager, with Chasmops sp., *Asaphus lundibundus* Tqt., *Illaenus fallax* Holm, *I. gigas* Holm, and *Caryocystis granatum* Wbg. According to Moberg the Chasmops limestone is in places found resting on the Orthoceras limestone.

Above the Chasmops zone, but never seen in contact with it, is the Brachiopod shale, from which only a few determinable fossils have been obtained, among them *Encrinurus multisegmentatus* Portl., *Atrypa crassicosta* Dalm., *Leptaena rhomboidalis* Wilckens, and *Plasmopora conferta* Milne Edwards & Haime.

Gästrickland.

Nearly all the fossils from this region have been obtained from boulders found in the drift (Wiman, 89), but the record is of considerable interest, from its rather close similarity to the Esthonian development. It appears to be the only part of Sweden where the Lower Cambrian was developed in a region where the Middle Cambrian was absent. The Chironkalk seems also to have been developed, in part, as a Linsenschicht (corresponding to the Upper Linsenschicht of the East Baltic) and the Chasmopskalk appears to have a development comparable to a part of C_1 of the Russian section.

Unfortunately only the strata from the Ceratopyge limestone to the Limbata limestone are found in place.

The Lower Cambrian is indicated by boulders with fragments of Olenellus, Agraulos, Ellipsocephalus, and Mickwitzia.

The Obolus sandstone is indicated by boulders.

Fragments of shale with *Ceratopyge forficula* and two species of Shumardia have been found.

The Ceratopyge limestone is in place on the Island Limon and is .83 meters thick. It contains the usual fossils.

Above this limestone is a clay with glauconite and nodules of limestone. It is 1.17 meters thick and contains few fossils, Lingula ? sp., Acrotreta sp., and Torellella sp. being the only ones reported. This corresponds to the "Glauconite sand" of Esthonia. By Wiman it is united with the Ceratopyge limestone rather than with the Planilimbata limestone above.

The Planilimbata limestone is described as being brownish red in color, with green, violet, and yellow spots and streaks, thus reminding one strongly of the same stratum on the Walchow. It is 3.5 meters in thickness. A rather large fauna is reported, including, *Pliomera actinura, Megalaspis planilimbata, Niobe laeviceps, Harpina excavata,* and *Orthis christianiae,* reminding one of the fauna which Lamansky found at the top of the "Glauconite sand" at Papowka.

The Limbatakalk is a lighter colored rock than the limestone below, and may be gray. It has a thickness of 5.45 meters. *Megalaspis limbata* and other fossils are present.

The Expansuskalk is known from boulders which contain many fossils, including the typical *Asaphus expansus, A. raniceps, Megalaspis acuticauda, M. heros, Lycophoria nucella,* etc.

The Gigaskalk is represented by a single boulder.

The Platyuruskalk is usually found as boulders of red limestone, and along with *Asaphus platyurus* contains many cephalopods, such as *Orthoceras conicum, Vaginoceras wahlenbergi, Lituites lituus,* etc.

The Chiron kalk is found in boulders, sometimes containing "linsen." The fauna contains *Asaphus kowalewski, A. cornutus, Illaenus chiron, I. schmidti,* and *Christiania oblonga,* and distinctly suggests the C_1 of Russia.

The older Chasmopskalk is lithologically like the Chironkalk, and in the boulders are found *Porambonites schmidti, Platystrophia lynx, Christiania oblonga,* Echinosphaerites, *Ptilograptus suecicus,* Climacograptus, and Diplograptus.

The boulders assigned to the younger Chasmopskalk or Macrouruskalk contain among others, *Chasmops maxima, Illaenus fallax, I. oblongatus, Porambonites ventricosus,* and *Platystrophia lynx.*

Boulders of the so-called "Ostseekalk," also occur which, in the North Baltic area, is partly fine-grained "lithographic stone" comparable to the Wesenberg limestone of Esthonia, while other boulders are of a different sort.

Wiman lists the fossils found in a large number of these boulders, which would seem to have been derived from formations very similar to the Kegel, Wesenberg, Lyckholm, and Borkholm of Esthonia.

Interesting species are *Chasmops wesenbergensis, Encrinurus seebachi, Lichas eichwaldi,* and *Clitambonites wesenbergensis,* all of which occur in the Wesenberg at Wesenberg.

Cyclocrinites schmidti and *C. balticus* of course suggest the Kegel, while *Platystrophia lynx* and *Oxoplecia dorsata* occurring together, remind one of the Kuckers.

Encrinurus multisegmentatus, Lichas laxatus, Tetradium wrangeli, Atrypa imbricata, and *Halysites parallelus* are all typical species of the Lyckholm.

Dalecarlia.

Miss Elsa Warburg (84), gives the following section as typical of the region.

Leptaena limestone		
Trinucleus shales	Red Trinucleus shale	15 m.
	Gray limestone	5–9 m.
	Black Trinucleus shale	6 m.
	Masur limestone	9–15 m.
Chasmops limestone	Macrourus limestone	9 m.
	Cystidean ls.	15 m.+
Orthoceras limestone 30–50 m.	Ancistroceras ls.	Upper gray Orthoceras limestone.
	Chiron ls.	
	Platyurus ls.	Upper red limestone.
	Gigas ls.	
	Asaphus ls.	Lower gray limestone.
	Limbata ls.	Lower red limestone.
	Planilimbata ls.	3.08 m.
Ceratopyge limestone	Ceratopyge ls.	.14–.16 m.
	Glauconite sand	.10 m.
	Obolus conglomerate	.15–.80 m.

In Dalecarlia there is no Cambrian, the Obolus conglomerate resting on the granite. It contains *Obolus apollinis* and is followed by a thin bed of greenish gray glauconitic clay-shale which contains some fragments of Obolus. Above comes a thin bed of glauconitic limestone which contains Obolus fragments and *Lycophoria laevis* Stolley. This Wiman correlates with the Ceratopyge limestone on the basis of the latter fossil.

At a single locality (Skattungbyn) Törnquist found in shales with interbedded slabs of limestone, *Tetragraptus serra, T. quadribrachiatus, Dichograptus octobrachiatus, Phyllograptus densus,* and three species of Didymograptus. The limestone contained *Pliomera törnquisti* Holm, *Megalaspides dalecarlica, Ampyx pater,* and *Agnostus törnquisti* Holm. In general however, the Planilimbatakalk is present, followed by the Limbata limestone. *Megalaspis planilimbata, M. limbata,*

Niobe laeviceps, and *Nileus armadillo* are found in these strata. The Asaphus limestone contains the typical species, *Asaphus expansus*, *Lycophoria nucella*, etc., and it may be noted that the Lower Linsenschicht is developed in this district. The Gigas and Platyurus limestones have many cephalopods, but few trilobites. Both the Chiron and Ancistroceras limestones contain their typical fossils and are followed by fifteen meters of limestone containing *Chasmops odini*, *Echinosphaerites aurantium*, and *Oxoplecia dorsata*.

The Macrourus limestone contains *Chasmops maxima* Schmidt.

The black Trinucleus shale contains *Trinucleus seticornis*, *Calymene trinucleina* Linrs., *Remopleurides radians* Barr., *Dalmanella argentea* His., and the graptolites *Dicellograptus anceps*, *Diplograptus pristis*, *D. truncatus*, and *Lasiograptus margaritatus*. The gray limestone is reported as containing numerous fossils, which however, occur only as fragments, and I have seen no list.

The red Trinucleus shale contains few fossils. *Remopleurides dorsospinifer*, *Proetus brevifrons*, *Agnostus trinodus*, *Trinucleus*, and *Pseudosphaerexochus laticeps* have been reported. The Leptaena limestone contains a very large fauna, comparable to that of the Lyckholm and Borkholm. There has been a great deal of discussion about the relative positions of the Leptaena limestone and Trinucleus shale in Dalecarlia. Although their faunas are quite different, yet both are characterized by an influx of Bohemian species, and both show the beginnings of a fauna like the Silurian. Furthermore, the presence of *Dicellograptus anceps* and *D. complanatus* are indicative of the youngest Ordovician age of the Trinucleus shales. The Leptaena limestone seems to show the physical characteristics of a "reef," though not perhaps of a coral reef, as Nathorst has suggested.

Västergötland.

The strata of the third belt are best exposed in Västergötland where the Cambrian, Ordovician, and Silurian rocks are practically horizontal and well shown on the sides of small "mountains" in which they have been protected from erosion by a capping sheet of diabase. On account of its quarries, Kinnekulle presents unusual opportunities for studying the Orthoceras limestone and the section there is one of the classic ones in Swedish geology. Throughout this region the Ordovician rests upon Upper Cambrian formations, and the Dictyonema shales are usually either very feebly developed or entirely

absent, and the Obolus sandstone has not been reported at all. At most localities the Ceratopyge limestone has a much better development than in the more northern belts, though in a few places it is entirely absent. In most sections, the Planilimbata limestone is absent and the graptolite-bearing shales replace it. The Asaphus limestone of this region is similar to that of Oeland and unlike that of other regions in that *Asaphus expansus* itself is absent from the fauna and the Asaphuskalk is divided into two members by a stratum which is almost entirely made up of the cystid *Sphaeronis pomum* Gyllenhahl.

Kinnekulle.

Ordovician	Brachiopodenschiefer	5 meters.
	Trinucleusschiefer	32 meters.
	Chasmopskalk	10 meters.
	Orthocerenkalk	52 meters.
	Underer Didymograptusschiefer	9 meters.
	Ceratopygekalk	1 meter.

The Ceratopyge limestone is a light gray limestone with light green glauconite and considerable pyrite in certain layers. Beside the typical fossils, which are somewhat abundant, *Lycophoria laevis* Stolley has been reported from this locality by Wiman (90).

The Orthoceras limestone here has been subdivided into four divisions, on the basis of color.

The lower twenty meters are of a deep red color and are known as the "Lower Red." Above is found a band three meters in thickness of light gray limestone, the "Lower Gray." At the top of this there is a sudden change again to deep red limestone and shale, not well exposed except for the two meters at the base, but perhaps thirteen meters thick. This is the "Upper Red," and it is followed by the "Upper Gray," sixteen meters of which could be measured. Fossils are common in the lower part of the Lower Red" and in the "Lower Gray" but rather rare elsewhere, and it does not seem to have been possible so far to make exact subdivisions on the basis of fossils. The color divisions do not, however, seem to correspond to the subdivisions which would be made on the basis of the fauna. The "Lower Gray" includes the "Sphaeronis bank" and with the upper part of the "Lower Red" and the lower part of the "Upper Red," represents the Asaphuskalk. On the basis of fossils it would appear that all the usual zones of the Orthoceras limestone, except the Planilimbatakalk and possibly the Gigaskalk, are present.

Limbatakalk — The greater part of the "Lower Red" probably belongs to this zone. *Megalaspis limbata, Nileus armadillo,* and *Symphysurus palpebrosus* are common here, and a number of other species were collected.

Asaphuskalk — I did not find fossils other than *Sphaeronis pomum* and *Megalaspis heros* very common in this zone. Several other species have been reported, among them *Phaeops sclerops, Cyrtometopus clavifrons, Asaphus raniceps maximus,* etc. The numerous cephalopods assigned to this zone in lists seemed to be derived from the lower part of the "Upper Red" and possibly to indicate the Gigas rather than the Asaphuskalk. Among these are *Vaginoceras wahlenbergi* (Foord), *Bathmoceras linnarssoni* (Ang.), and *Estonioceras proteus* Holm. *Megalaspis gigas* itself has not been found, but the cephalopods mentioned indicate, I believe, its zone.

Platyuruskalk — *Asaphus platyurus* and *Orthoceras tortum* are reported from the upper part of the "Upper Red."

Chironkalk — The "Upper Gray" evidently represents the zones of both *Illaenus chiron* and Ancistroceras. *Illaenus chiron* Holm, *Ogygiocaris dilatata sarsi* Angelin, *Ancistroceras undulatum* Boll, and *Discoceras teres* Eichwald have been reported.

The next formation, the Chasmopskalk, is not exposed on the side of Kinnekulle which I visited, but it is reported as being a dark green graptolite-bearing shale with lenses and layers of impure limestone. The graptolites are not listed, but the limestone is said to contain Chasmops sp., *Remopleurides sexlineatus, Ptychopyge? glabrata, Ampyx rostratus, Echinosphaerites aurantium,* etc. The thickness is ten meters.

The Trinucleus shales, which are not well exposed, are said to be thirty-two meters thick and consist of two shales separated by a thin limestone. The lower twelve meters consist of black and greenish shales separated by two meters of limestone from eighteen meters of the red shale above. Among the forms listed from the upper shales are *Remopleurides radians, Cybele verrucosa, Trinucleus wahlenbergi,* and *Dionide euglypha.*

The Brachiopodenschiefer are said to be represented by twenty-six meters of calcareous shale below, followed by two and four tenths meters of impure sandy limestone. Fossils do not appear to be common, *Dalmanites mucronatus, D. pulchellus,* and *Homalonotus platynotus* being the chief ones reported.

I visited Älleberg, but found it impossible to get good fossils without spending more time than was at my disposal.

Here the upper Trinucleus shales, also called the Staurocephalus shales, are reported to be very fossiliferous and add *Staurocephalus clavifrons*, *Acidaspis centrina*, and *Phillipsia parabola* to the list of species found at Kinnekulle.

Oeland.

The Ordovician on Oeland rests on Upper or Middle Cambrian strata and the basal member may be either the Dictyonema shale or the Ceratopyge shale. This has been especially well brought out in an instructive diagram by Fearnsides (59). The most complete section of the "Ceratopyge Region" and Cambrian is shown in southern Oeland, where, ignoring subzones, the following strata are found, in descending order.

Ordovician	Glauconite shale. Ceratopyge limestone. Glauconite shale. Shumardia shale. Dictyonema shale.
Upper Cambrian	Peltura limestone. Olenus shale.
Middle Cambrian	Paradoxides forchammeri zone. P. tessini zone. P. oelandicus zone.

It has been shown that in passing northward both the Dictyonema and Shumardia shales pinch out, but at the northern end of the section both come in again, the Dictyonema shale being in certain localities replaced by the Obolus conglomerate. At the southern end of the island the Ordovician rests upon the youngest known beds (zone of *Peltura scaraboides*) of the Upper Cambrian. About midway between the northern and southern ends the Peltura beds disappear and the Ordovician rests for a short distance on the lower part of the Upper Cambrian. From Borgholm for several miles north the Ordovician rests on the next lower zone of the Cambrian, the *Paradoxides forchammeri* zone of the Middle Cambrian. Still further north this gives place to the next lower zone, that of *P. tessini*. The strata of the *Paradoxides tessini* zone are here sandy, and it is where the Ordovician rests on them that the Obolus conglomerate is developed, thus indicating the local origin of the material in the Lower Ordovician.

Finally at the northern end of the island, the Ordovician rests on strata of the lowest of the Middle Cambrian zones, that with *Paradoxides oelandicus*. This section shows very clearly that there was an uplift, tilting, and erosion after the deposition of the Peltura beds of the Upper Cambrian and before the deposition of the Dictyonema shales of the Ordovician, and thus emphasizing once more that the natural place to draw the boundary between the Ordovician and Cambrian is at the base of the Dictyonema shales (or the equivalent Obolus sandstone).

In spite of the considerable amount of work which has been done on Oeland, I am unable to find that any section has been published in which the thicknesses of all the strata have been given.

The youngest strata found in place in Oeland belong to the Lower Chasmops or Echinosphaerites limestone, but the Macrourus limestone, Trinucleus shale, and Leptaena limestone (Lyckholm) are all represented by numerous boulders.

The Echinosphaerites limestone is seen only in northern Oeland, and only *Echinosphaerites aurantium* and *Illaenus chiron* seem to be reported from it.

The Orthoceras limestone is very well developed on the island and it was here that its subdivision on the basis of fossils was first accomplished by Moberg (71). The zones, in descending order are: —

Ancistroceras limestone. The fauna is reported to contain *Ancistroceras undulatum* Boll, Remopleurides, Ptychopyge, *Nileus armadillo*, *Illaenus chiron*, and Orthoceras.

Chiron limestone. This is a limestone containing *Illaenus chiron* Holm, *Ptychopyge aciculata* Ang., *P. testicaudata* Steinh., *Megalaspis pagiata* Tqst., *Ogygiocaris dilatata sarsi* Ang., *Telephus bicuspis* Ang., *Lituites lituus* Monf., and *Didymograptus geminus* His.

Platyurus limestone. This zone has only a few fossils reported, these being *Asaphus platyurus maximus*, *Ptychopyge brachyrachis* Remele, *Rhynchorthoceras* cf. *angelini* Boll., *Echinosphaerites aurantium* Gyllenhahl, and *Hyolithes inaequistriatus* Remele.

From the Gigas limestone, only *Megalaspis gigas* Ang. has been reported.

Upper Asaphus limestone. Moberg states that this is a reddish, rarely white, crystalline limestone with a large fauna of small, mostly undescribed trilobites, and that there is nothing elsewhere which exactly corresponds to this zone. He cites *Nieszkowskia tumidus*, Asaphus sp., *Illaenus esmarki*, *I. centrotus*, *Nileus armadillo*, and *Niobe frontalis* as among the species present.

Below this is the stratum filled with *Sphaeronis pomum* Gyllenh. as at Kinnekulle.

Lower Asaphus limestone. This is a gray limestone from which *Pterygometopus sclerops, Megalaspis heros, Ptychopyge applanata, Niobe frontalis, Illaenus esmarki, Ampyx nasutus, Orthis obtusa,* and *Glyptocystites* cf. *leuchtenbergi* have been reported. *Asaphus expansus* is not found in Oeland.

Holm (65), has described, from a glauconitic gray limestone at Hälludden near Böda in northern Oeland, *Isograptus gibberulus* (Nicholson), *Didymograptus minutus* Tqst., *Tetragraptus bigsbyi* Hall, and *Phyllograptus angustifolius* Hall. The limestone containing these fossils is said to belong to the Lower Asaphus zone, but may possibly be in the Limbata zone.

Limbata limestone. From this zone Moberg reports *Megalaspis limbata, Niobe laeviceps,* two pelecypods, two gastropods, and "*Rhynchonella*" *digitata* Leuchtenberg.

Planilimbata limestone. From this limestone, which is often quite glauconitic, *Megalaspis planilimbata* Ang. and *Holometopus limbatus* Ang. have been obtained.

The Ceratopyge (76) zone is well developed in Oeland, but, as has previously been mentioned, it is variable in its constitution. In the southern half of the island a limestone is present in the upper part, included between two glauconitic shales, and beneath the lower shale is another shale characterized by Shumardia. In the northern half of the island the Shumardia shale is absent, also the limestone, and there remains only a shale bearing Ceratopyge. The total thickness seems to be small, with a maximum of about two meters.

The Dictyonema shale is, as stated above, present in both the northern and southern portions of the island, but absent for a considerable space through the middle. The thickness in the southern part of the island is about two meters.

Scania.

In Scania the strata of the Ordovician consist very largely of graptolite-bearing shales, these shales resting upon the Olenus shales of the Upper Cambrian. At various horizons, however, beds of limestone are intercalated in the shales. No one region presents a complete section, and the following composite section contains some beds which are found only in East Scania, some found only in West

Scania, while others are developed in both regions. The table is an amplification of one given by Moberg (75).

Trinucleus or Upper Dicellograptus shales	Zone of *Phacops eucentra* and *Staurocephalus clavifrons*. Zone of *Amypx portlocki*.
Chasmops or Middle Dicellograptus shales (with limestone)	Zone of *Pleurograptus linearis*. Zone of *Calymene dilatata* and *Dicranograptus clingani*.
Lower Dicellograptus shales	Zone of *Nemagraptus gracilis*. Zone of *Climacograptus putillus*. Zone of *Glossograptus hincksi*.
Upper Didymograptus shales	Zone of *Didymograptus geminus*. Zone of *Phyllograptus* cf. *typus*.
Orthoceras limestone	
Lower Didymograptus shales	Zone of *Isograptus gibberulus*. Zone of *Phyllograptus angustifolius*. Zone of *Didymograptus balticus*. Zone of *Tetragraptus phyllograptoides*.
Ceratopyge limestone	
Shumardia shale	
Dictyonema shale	

The fauna of the Trinucleus beds has been described by Olin (79), who enumerates many species. Of trilobites forty-three species were listed, and it is of particular interest to note that twelve of these are species common to Sweden and Bohemia. Prominent among such species are *Cheirurus pectinifer* Barrande, *Remopleurides radians* Barr., *Calymene incerta* Barr., *C. pulchra* Beyr., *Phillipsia parabola* Barr., "*Asaphus*" *ingens* Barr., *Trinucleus bucklandi* Barr., *Ampyx gratus* Barr., *A. portlocki* Barr., *A. tenellus* Barr., and *Aeglina rediviva* Barr. In addition to these common species, the genera Aeria, Staurocephalus, and Dionide in themselves suggest the Bohemian fauna. Other important species in the fauna are *Phacops* (*Dalmanites*) *eucentra* Ang., *Agnostus trinodus* Salter, and *Stygina latifrons* Portlock. The important graptolites are *Dicellograptus complanatus* Lapw., and *Diplograptus truncatus* Lapw.

The Chasmops beds contain a rather small fauna, but although there are many limestone bands in the shales, there are fewer trilobites and more graptolites. Olin lists among others *Calymene dilatata*

Tullb., *Remopleurides sexlineatus* Ang., *Ampyx rostratus* Sars, *Dalmanella argentea* (His.), *Corynoides calicularis* Nich., *Dicranograptus clingani* Carr., *Diplograptus quadrimucronatus* Hall, *Climacograptus scharenbergi* Lapw., and *Ptychopyge ? glabrata* Ang. The zone of *Dicranograptus clingani* is at the base of the Chasmops beds, and the zone of *Pleurograptus linearis* at the top.

The fauna of the Lower Dicellograptus shales has been monographed by Hadding (60), who lists the following as characteristic fossils of the thin-bedded gray-black shales which make up the strata of the three subzones in Scania.

Subzone of *Nemagraptus gracilis.*— *Nemagraptus gracilis remotus* Elles & Wood, *Lasiograptus mucronatus* Hall, *Obolus elatus* Hadding, *Plectambonites sericeus restrictus* Hadding.

Climacograptus putillus zone.— *Climacograptus putillus* Hall, *C. caudatus* Lapw., *Dicellograptus vagus* Hadding, and *Dicranograptus irregularis* Hadding.

Glossograptus hincksi zone.— *Glossograptus hincksi* Hopk., *Cryptograptus lanceolatus* Hadding, and *Diplograptus perexcavatus* Lapw.

The Upper Didymograptus beds consist of green and gray shales and the fauna seems to be incompletely known.

In the *Didymograptus geminus* beds.— *D. geminus* Hisinger, *Lonchograptus ovatus* Tullb., *Climacograptus confertus* Lapw., *Pterograptus scanicus* Moberg, *P. elegans* Holm, and species of Diplograptus and Cryptograptus have been reported.

From the lower zone.— *Phyllograptus* cf. *typus*, *Didymograptus* cf. *bifidus*, *Climacograptus* and Cryptograptus are reported. It seems to be a sort of transition zone, in which the Diprionian graptolites which are so abundant in the beds above make their first appearance, but accompanied by some of the survivors of the more ancient fauna.

The Orthoceras limestone is a hard, rather pure, dark blue limestone and is at present inadequately exposed. Angelin (58) described twenty species of trilobites from the quarries at Fågelsång, some of the more important of which are **Ampyx nasutus* Dalm, *Asaphus acuminatus* (Boeck), **Cyrtometopus clavifrons*, **Megalaspis limbata* (Sars and Boeck), **Nileus armadillo* Dalm, *Symphysurus palpebrosus* (Dalm), **Niobe frontalis* Ang., **Pterygometopus sclerops* (Dalm), *Trinucleus coscinorrhinus* Ang. The species marked with an asterisk occur in the Limbata or Expansus limestones of Sweden and in the zones $B_{II\beta}$ and $B_{III\alpha}$ of Russia.

According to Strandmark (81), beds of shale containing graptolites

occur between the limestone strata of the Orthoceras limestone, the species found being *Tetragraptus bigsbyi* Hall, *Didymograptus extensus* Hall, and *Phyllograptus cor* Strandmark.

The fossils of the Lower Didymograptus shales have been described by Törnquist (83). These shales are much better developed in southeastern Scania than about Lund.

The zone of *Isograptus gibberulus* contains *Isograptus gibberulus* Nich., *Didymograptus extensus* Hall, *D. patulus* Hall, and *D. mobergi* Tqst.

The zone of *Phyllograptus angustifolius* has *Didymograptus praenuntius* Tqst., *Phyllograptus angustifolius* Hall, and *Tetragraptus pendens praesagus* Tqst.

The zone with *Didymograptus balticus* has a larger fauna, among the species being *Didymograptus constrictus* Hall, *D. balticus* Tullb., *Tetragraptus quadribrachiatus* Hall, *Dichograptus octobrachiatus* Hall, and *Clonograptus subtilis* Tqst.

The lowest zone contains *Tetragraptus phyllograptoides* Linrs., *T. approximatus* Nich., *T. serra* (Brong.), *Didymograptus undulatus* Tqst., and *D. holmi* Tqst.

The Ceratopyge zone is poorly developed in Scania, but both the Ceratopyge limestone and Shumardia shale have been shown to be present, with the usual fossils.

The Dictyonema shales are subdivided into three zones.

C, zone with *Bryograptus kjerulfi* and *Dictyonema norvegica*.

B, zone with *Clonograptus tenellus* in four varieties.

A, zone of *Dictyonema flabelliforme* in which, interstratified with shales, are beds of limestone with *Hysterolenus törnquisti* and *H. levicaudus*.

Very little seems to be known of the thicknesses of strata in Scania. On seeing the outcrops in the field, one receives the impression that they are very small. In a boring made at Stabbarp, northeast of Lund, the Chasmops beds were encountered between eighty-six and ninety-two meters below the surface and shales of the *Phyllograptus* cf. *typus* zone at a depth of 102 meters, thus indicating a thickness of about ten meters for the Lower Dicellograptus shales.

At Jerrestad in eastern Scania Olin measured a section 425 cm. in thickness, all in the Trinucleus zone, and most sections which it is possible to measure are of this order or of less thickness.

Summary.

From the above summary of the sections in the principal Ordovician belts of Sweden, certain facts should appear.

It will be noted that the Dictyonema zone is present in almost all sections, and that the character of the deposit is controlled by the underlying beds, a fact which in itself is evidence of a cessation of sedimentation, uplift, and erosion. In North Oeland, where the basement beds are the *Paradoxides tessini* sandstone, an Obolus sandstone is developed, and in the northern belt, Dalecarlia-Gästrikland, where the older strata are pre-Cambrian crystallines and Lower Cambrian sandstones, one finds Obolus conglomerate and Obolus sandstone. That the Obolus sandstone is of the same age as the Dictyonema shale is of course abundantly proved by their interstratification with each other at several places in Esthonia. In southern Oeland, in Scania, and at Christiania, where the underlying strata are the black shales and limestones of the Upper Cambrian, the Dictyonema zone is developed as a shale without sand and has even, in places, irregular layers of limestone.

Over a certain area, in Nerike and part of Västergötland, the Dictyonema zone is absent. Thus, at Kinnekulle the Ceratopyge limestone rests upon the limestone and shale of the Upper Cambrian, at Ekedalen the Planilimbata limestone rests directly on the Upper Cambrian, and at Hunneberg the Ceratopyge limestone rests on the Upper Cambrian limestone in most places, though in some spots about three inches of shale belonging to the Dictyonema zone have been reported. The arrangement of these localities free from Dictyonema deposits suggest a large, low lying island composed of uplifted Upper Cambrian strata, which was progressively submerged during Lower Ordovician time, but not completely covered till toward the end of Planilimbata time. Correlated with this may be the distribution of the Lower Didymograptus shale.

As has already been pointed out repeatedly by the Swedish geologists, when the Lower Didymograptus shales are present in any section, the Planilimbata limestone is absent, and when the latter is present, the former is absent. This has naturally led to the deduction that the two formations were deposited at the same time and owe their dissimilar faunas to the very different conditions of sedimentation. On this point, the evidence, though strong, does not seem to be absolutely conclusive. It would seem that, should it happen that lime-

stone were found interstratified with the graptolite shale, it should contain some at least of the species found in the strata where limestone only was deposited. In Dalecarlia, Holm (62), found a trilobite fauna in limestone interstratified with the Lower Didymograptus shales. Six species of trilobites were identified, and five of the species, *Pliomera törnquisti, Megalaspides dalecarlica, Ampyx pater, Agnostus törnquisti,* and *Trilobites brevifrons* were new and are all restricted to this one locality. The sixth species, *Niobe laeviceps* Dalman is not a guide fossil, ranging from the Ceratopyge limestone to the Asaphus limestone. The pygidium of *Pliomera törnquisti* is not known but the cephalon and thorax show that it is not a true Pliomera but a Cyrtometopus allied to the forms found in the Ceratopyge limestone. Similar species are, however, found in higher strata. Megalaspides is not yet definitely placed outside this occurrence in Dalecarlia. Wiman (88), has described *Megalaspides nericiensis* from the Shumardia shale in Nerike, but there is some doubt as to whether this Shumardia shale belongs to the Ceratopyge zone or to a horizon in the Planilimbata limestone.

Wiman (89), also reports pygidia of Megalaspides from boulders of Planilimbata limestone in Gästrikländ, and Lamansky (29) described *Megalaspides schmidti* from a pygidium found in B_1 at Papowka. Identifications based on pygidia alone seem rather unsafe in this genus, the pygidium being so Asaphus-like. The genus has not hitherto been suspected in the Ceratopyge limestone, but at Hunneburg I found a large hypostoma of the "forked" type in the same strata with Euloma and Symphysurus, and as no other member of the Asaphinae is known at so low a horizon, it of course suggests Megalaspides. *Agnostus törnquisti* and *Trilobites brevifrons* are of no value in the discussion. *Ampyx pater* is similar to *Ampyx nasutus* of the Limbata and Asaphus limestones rather than to the species so far described from the Ceratopyge limestone.

The fauna found by Holm in Dalecarlia is then not very useful in the correlation of the Lower Didymograptus beds with the Planilimbata limestone. It contains no species restricted to the Planilimbata limestone, and the general composition of the fauna is such that, lacking a guide fossil of either, it could be referred to the strata either above or below it. Over most of Dalecarlia the Planilimbata limestone is present, but very poor in fossils. In Jemtland, as indicated on page 208 there does seem to be some mingling of the species of the Lower Didymograptus shales with those of the Planilimbata limestone.

The Didymograptus shale is absent from Oeland, is best developed

in eastern Scania, present in western Scania, well developed in Västergötland at Hunneberg and Kinnekulle, and present though less developed in other places. As previously noted, the shale is absent at Ekedalen, and Fearnsides has pointed out that the shale thickens in going away from Sköfde and Ekedalen. Munthe gives the following thicknesses at places on the Sköfde sheet of the Geologic Map: Ulunds, .6 meters, Bäckagarden .23 meters, Kapplunda .2 meters, Persberg, absent, Skultorps Norra .9 meters. At Klefda in the western Falbygden region, not far from Falköping, the thickness is three meters, at Hunneberg, eleven meters (capped with diabase), and at Kinnekulle, ten meters. As to fauna, it is only in eastern Scania that the four subfaunules are developed. Here one sees, in descending order:— (4), zone of *Isograptus gibberulus*, (3), zone of *Phyllograptus angustifolius*. (2), zone of *Didymograptus balticus*. (1), zone of *Tetragraptus phyllograptoides*.

In connection with the thinning of the shales toward Ekedalen it is important to note that at Hunneberg one finds the zones 1 and 2, at Kinnekulle 1, 2, and 3, the Limbata limestone succeeding the shale, but in the thin sections in the Sköfde area *Phyllograptus angustifolius* is reported as the most common graptolite, indicating the presence there of zone 3. In other words, the shale has thinned by the loss of the lower members, thus showing overlap in that direction and sustaining the idea that there was an island of Cambrian strata here in early Ordovician times. The Ceratopyge formation also thins in this direction, as shown by Munthe's measurements in the Sköfde sheet: Ulunda .3 meters, Backagarden .12, Kapplunda .4, Persberg .3, Skultorps Norra .9 and Skultorps Sodra .15. It has been argued (Wiman, 90) that the foot of conglomeratic and glauconitic limestone resting on the Cambrian at Ekedalen represented the Ceratopyge limestone, but this seems very improbable both on faunal and stratigraphic grounds.

It has been suggested that the lower part of the Lower Didymograptus beds replace the Ceratopyge limestone in certain regions, but the very general occurrence of the *Tetragraptus phyllograptoides* faunule in shales resting on the youngest of the Ceratopyge zones negatives this idea. That the Limbata limestone does replace the upper part of the shale is, however, readily shown by the occurrence of the fauna of the *Isograptus gibberulus* subzone in or above the Limbata limestone on Oeland.

In connection with the development of the Orthoceras limestone, certain things should be noted. For instance, in those sections where

the Orthoceras limestone is thickest, as on Oeland or at Kinnekulle, *Asaphus expansus*, the guide fossil of the "Expansusschicht" is absent; and there is found, above the strata containing a fauna which includes a part of the species usually found associated with *Asaphus expansus*, a layer with such quantities of the cystid *Sphaeronis pomum* as to make a veritable cystid reef. No such reef is seen where *Asaphus expansus* is present, as in Östergötland or the Christiania district. Both Sphaeronis and *Asaphus expansus* are reported from Dalecarlia, but, according to Törnquist the former species is exceedingly rare, and not quite typical, and that district will probably not prove to be an exception to the general rule.

Very little has been done toward working out the details of the various sections in the Orthoceras limestone, so that the sections at Kinnekulle and Oeland are really the only ones which can be compared. On Oeland, one finds above the bed with *Sphaeronis pomum* the Upper Asaphus limestone, with numerous undescribed trilobites. Moberg states that this zone occurs nowhere else and it certainly is not present at Kinnekulle, where a cephalopod fauna is found in the red limestone above the Sphaeronis bed. This cephalopod fauna is that normally found in the Gigas limestone, and it seems that there is in the Oeland section a zone which is lacking at Kinnekulle. Whether the absence of *Asaphus expansus* from the thick sections is explainable by the predominance of red sediments, or whether the Expansus beds are actually absent is not at present apparent. It should be observed that the extra thickness in these great sections is largely accounted for by the unusual development of the Planilimbata limestone, though of course the added zones above the Gigas limestone have something to do with it.

In Oeland, at Kinnekulle, and in Delarne, one finds considerable limestone above the Gigas limestone, which by the Swedish geologists is included in the Orthoceras limestone. This limestone contains three faunal zones, according to the Swedish geologists, but the faunas of the three seem very much alike. The lower zone contains *Asaphus platyurus* and *Echinosphaerites aurantium*, fossils found in $C_{1\alpha}$ of Russia, and *Illaenus chiron* is found in $C_{1\beta}$ of that country, but the other guide fossils are mostly species not found in Russia. The presence of *Didymograptus geminus* in the middle zone of the three in Oeland is noteworthy, for it serves to complete the parallelization of the Scanian and Oeland sections.

The presence of Ogygiocaris, which seems to have an exceedingly narrow vertical range, in the Nemagraptus zone in Jemtland and in the

Chiron limestone of Kinnekulle and Oeland, serves to indicate that the upper part of the Orthoceras limestone in these localities is the equivalent of the *Nemagraptus gracilis* shale as well as the Geminus shale. And the correlation of the Chasmops limestone with the graptolite shales of the *Dicranograptus clingani* and *Pleurograptus linearis* zones is assured by the presence of several species common to the two types of deposits.

CORRELATION OF THE AMERICAN WITH THE EUROPEAN FORMATIONS.

In attempting a correlation over such a distance one is of course obliged to depend very largely on fossils; and it is necessary to assume an hypothesis which all the evidence seems to support, namely, that cosmopolitan faunas reach their wide distribution within a very short space of time. In the present case, it is necessary to depend very largely upon the graptolites which seem to be more widespread than any of the other organisms. Graptolites are, of course, almost absent from Russia, so that it is necessary to correlate the Russian with the Swedish sections by means of other fossils. The trilobites, being best known, have been used most, but in certain cases species of brachiopods, cystids, or cephalopods have proved of prime value.

After making many groupings of the formations and testing many tentative correlations, it has seemed that the most logical arrangement is secured if the principal weight is given to the graptolites. It appears that these organisms had spread very much more rapidly than any of the other animals, except for a few thin-shelled brachiopods and trilobites which may have been dispersed by the same agency as the graptolites. When relatively short distances are in question, it seems that the bottom dwelling animals were able to keep pace in their migrations with the graptolites, at least sufficiently closely so that we detect no difference in the geological record, but when long distances are traversed, the bottom animals lag very considerably behind. Striking cases are those of Shumardia, which preceded the first Tetragraptus fauna in Scandinavia, and reached America only with the last Tetragraptus and the first Diplograptus, and of Echinosphaerites, which preceded the *Nemagraptus gracilis* fauna in Scandinavia and followed it in America.

Lower Ordovician.

The drawing of the lower boundary of the Ordovician at the base of the shales with *Dictyonema flabelliforme* instead of at the top of that zone is due to Moberg (73), and seems to have been suggested to him in the first instance by the discovery low in the zone of a trilobite (*Hysterolenus törnquisti*), which bore a marked resemblance to Ceratopyge. The suggestion was a remarkably good one and is borne out both by faunal and stratigraphic relations.

On the faunal side, one may cite the occurrence in this zone of the oldest graptolites, thus marking the introduction of an entirely new faunal element. Also, a few species are common to the shales of the upper part of the zone and the Shumardia or Ceratopyge shales at the base of the Ceratopyge zone.

The best argument is, however, based upon the evidence which the geographical distribution of the deposits show of a great transgression of the sea at this time, and the evidence of preceding erosion. This evidence has already been detailed above, and it is necessary here only to call to mind the conditions in the several regions.

In Esthonia the Dictyonema shale is interstratified with the Obolus sandstone, leaving no doubt that the two are of the same age. The Obolus sandstone, with conglomerate at the base in places, rests on Lower Cambrian sandstone.

In Oeland, in passing from north to south, the base of the Ordovician (Obolus sandstone, Ceratopyge shale, and Dictyonema shale) rests on successively higher and higher strata, varying in age from lower Middle Cambrian to upper Upper Cambrian, the Obolus sandstone being developed over the Middle Cambrian Tessini sandstone.

In Dalecarlia, the Obolus sandstone overlaps onto the crystalline rocks, but eastward in Gästrikland boulders of both Lower Cambrian sandstone and of Obolus sandstone indicate that conditions there were formerly as in Esthonia.

These facts show very clearly that at the end of the Cambrian there was uplift accompanied by some, though probably not great tilting, and a considerable amount of erosion, before the deposition of the strata of the Dictyonema zone.

In America, the *Dictyonema flabelliforme* fauna is known from a number of localities in the northeastern part of the United States and Canada, but nowhere are these strata found in such position that their relation to other strata can be definitely determined.

Ruedemann (115) has summarized all that is known about its occurrence in this country, and he, Matthew (104), and Hahn (103), have pointed out the similarity of development of subzones at St. John, New Brunswick, and Scandinavia. Present evidence indicates that the *Dictyonema flabelliforme* fauna is the oldest of the Ordovician faunas in both Europe and America, though there is a possibility that the strata with the Acerocare fauna in Scania and the Niobe fauna in Wales may have to be added to the Ordovician series.

Brögger (99), attempted a correlation of the Ceratopyge zone with certain strata in America but though his paper was extremely suggestive, no very definite correlations were at the time possible. And even now, we know no typically developed Ceratopyge fauna in America. Walcott (120) has described a trilobite from the lower part of the Goodsir formation of British Columbia as *Ceratopyge canadensis*, and though it seems very doubtful if this is a Ceratopyge, it probably belongs to the Tremadoc fauna. The writer has described from the same region *Hemigyraspis mcconnelli* (110), a form indicative of the Asaphellus beds of the Tremadoc of Wales. I have also described, from the Tribes Hill of New York and the equivalent Stonehenge of Pennsylvania, species of Hemigyraspis and Symphysurus also indicative of the Ceratopyge fauna. This latter correlation is of considerable importance, for the Stonehenge is the lower member of the Beekmantown in western Central Pennsylvania. The Hemigyraspis fauna occurs in the upper twenty-seven feet of the Stonehenge, which has a thickness of 662 feet, and above the Stonehenge are 2570 feet of strata before the top of the Beekmantown is reached. In the lower Stonehenge, a Dictyonema has been found (Hahn, 103).

In Russia the Ceratopyge zone is probably not represented. There is of course a temptation to make the Glauconite sandstone the equivalent of the whole Ceratopyge zone, especially as one sees in Sweden glauconitic sands associated with the Ceratopyge limestone. In Dalecarlia there is a glauconite sand beneath the Ceratopyge limestone, but in Gästrikland, where the section is very like the Russian section, there is a glauconitic sand above the Ceratopyge limestone, and it seems very probable that this sand is an extension of that so well developed in Esthonia. It seems to belong with the Limbata limestone above. This sandstone is thickest in Esthonia, and probably indicates an emergence in that district so that there was some erosion, perhaps accounting for the absence of the Dictyonema shale at Narwa, and shore or shallow water conditions in Esthonia during the deposition of the Lower Didymograptus shales in Scandinavia.

The absence of the Lower Didymograptus fauna in Esthonia seems explainable on the basis of lack of suitable physical conditions. It is well known that the abundance of graptolites increases in proportion to the degree of fineness of grain and amount of carbonaceous material in shale. The Middle and Upper Cambrian strata of Sweden are vast storehouses of very fine grained, highly carbonaceous shale. Possibly these deposits extended at one time nearly or quite to Esthonia. As has been shown, the end of the Cambrian was a time of considerable denudation, and the Cambrian sediments could furnish a vast supply of black mud, which, on account of its fineness, could be transported long distances. Hence the widespread deposit of Dictyonema shales. The shales however, rapidly covered the sinking land, and were in turn covered, over large areas, by the Ceratopyge limestone, so that, when the Lower Didymograptus fauna occupied this region, only limited areas of Cambrian strata, such as the island already mentioned in Västergötland at Ekedalen and Sköfde, were subject to erosion. There may have been a small rather general uplift at this time, indicated in Sweden by the change from limestone to shale sedimentation, and in Esthonia by the glauconite sand. To consider the Dictyonema and Lower Didymograptus black shales as reworked Cambrian shales seems more plausible than to think of them as due to certain peculiar conditions under which black shales seem usually to be formed. In any event, Esthonia was at this time outside the territory which could be supplied with reworked upper Cambrian muds, while sands were immediately available and the graptolite fauna did not reach the region.

To correlate the Russian "Orthoceras limestone" (B_{II}, B_{III}) with any formation in America on the basis of graptolites is rather complicated but it can, I think, be done fairly satisfactorily. In the first place there is general agreement, on the evidence of numerous species of trilobites, cephalopods, and brachiopods common to both, that the zones from the Planilimbata limestone to the top of the Gigas limestone in Sweden and Norway are the equivalent of the zones B_{II} and B_{III} in Russia. As to the exact correlation of the subdivisions there is not so great unanimity of opinion, but as to the bounding formations, the Planilimbata limestone and the Gigas limestone on one side; and the Glauconite limestone ($B_{II\alpha}$) and the Orthoceras limestone ($B_{III\gamma}$), on the other, there can be no question.

In Sweden the position of this limestone in respect to the graptolite succession is definitely fixed. We know that the Planilimbata limestone succeeds the Ceratopyge zone, and that the *Tetragraptus phyllo-*

graptoides zone succeeds the Ceratopyge zone, and precedes the Limbata limestone. The Planilimbata limestone can not be older than the oldest of the Tetragraptus zones. On Oeland, *Isograptus gibberulus,* and other graptolites of the Lower Didymograptus zone occur in the Lower Asaphus limestone, which Lamansky correlates with the Russian zone $B_{III\beta}$. In Norway the Gigas limestone is followed by black shale with *Didymograptus geminus.* On Oeland, the Gigas limestone is followed by the Platyurus limestone, and that in turn by the Chiron limestone, which contains *Didymograptus geminus.* The top of the Gigas limestone, and likewise of the Orthoceras limestone ($B_{III\gamma}$) of Russia, is therefore somewhat older than the *Didymograptus geminus* fauna. In Scania, the *Didymograptus geminus* fauna is found in shales resting on other shales containing *Phyllograptus* cf. *typus* and *Didymograptus* cf. *bifidus.* This in turn rests upon the Orthoceras limestone of that region. This limestone, in turn follows shale with the *Isograptus gibberulus* fauna. The limestone contains a large trilobite fauna which, however, in our incomplete knowledge of the faunas of the Swedish "Orthoceras limestone," it is not safe to correlate directly with the faunas of other regions. Since it follows the zone with *Isograptus gibberulus,* one would naturally correlate the Orthoceras limestone of Scania with the Lower Asaphus limestone of Oeland. If this correlation is correct, then the *Phyllograptus* cf. *typus* beds of Scania would appear to represent some or all the Upper Asaphus limestone, Gigas limestone, and Platyurus limestone of Oeland. But for reasons to be given later, the Platyurus limestone is probably to be eliminated from this list. This does not of course, prove definitely that the Gigas limestone is of the age of *Phyllograptus* cf. *typus,* though there is a strong presumption, since both are older than the zone with *Didymograptus geminus.* Fortunately however, Schmidt found Phyllograptus in B_{III} in Esthonia, and Phyllograptus sp. has been reported from above the Gigas limestone of Norway.

The limestone of the Gigas and lower zones, down to the bottom of the Planilimbata zone of Sweden, and the zones B_{II} and B_{III} of Russia must therefore be placed within the range of Phyllograptus in the graptolite succession. It remains now to see what that means in the American sequence.

The occurrence of the Tetragraptus-Phyllograptus-Didymograptus fauna in the shales of the Lévis formation of Canada has long been known, and recent work by Ruedemann (115) and the writer (111) has shown the order of succession of the faunules within the formation. The relation of the Lévis to the Beekmantown of America

is, however, not yet fully settled, though evidence accumulated by Dr. Ulrich (119) shows that the Lévis and Beekmantown are probably of the same age. This evidence is based largely on the occurrence of graptolites in dolomite with a Beekmantown fauna near Smithville, Lawrence Co., Arkansas. At this locality, *Phyllograptus ilicifolius, P. angustifolius, Didymograptus bifidus,* and *D. amplus* have been found with brachiopods and fragments of trilobites. In a bed just above the one containing graptolites, *Plethospira cassina, Subulites obesus,* and *Eurystomites kellogi* were found. These latter fossils are characteristic of the Cassin limestone and occur about midway in the section of the Beekmantown on the eastern side of Lake Champlain. In Vermont the strata of the Beekmantown are principally limestone and dolomite, the total thickness being about 1200 feet, the top being unknown, as the upper beds were eroded before the deposition of the Chazy. The top of the Cassin limestone is 470 feet below the top of the Beekmantown and the formation is 100 feet thick. No graptolites have been found in the Beekmantown in Vermont. There seems no doubt however, that the mollusks cited above are characteristic of the Cassin and, therefore, the graptolites found in Arkansas belong in the Cassin or in an older formation, and are surely Beekmantown in age.

In England all the species of Phyllograptus and Tetragraptus are in the Arenig, and in America the various zones of the Lévis contain species of these genera, and all the zones are so knit together by common species that it seems quite evident that all belong to a continuous series. *Phyllograptus ilicifolius* is a long ranging species at Lévis, but *Didymograptus bifidus* is found in shale in the middle of the section. The fossils in Arkansas thus suggest that the middle of the Lévis corresponds to the middle of the Beekmantown, and that the two are approximately equivalent.

From these considerations one feels justified in concluding that all the strata characterized by Phyllograptus, *Didymograptus bifidus,* and Tetragraptus, both in Europe and America, are equivalent, and represent the deposits of Beekmantown (Arenig) time. It has been pointed out in the previous detailed discussions that the Dictyonema and Ceratopyge zones of Scandinavia are related to the strata overlying them, so that the final correlation would be that the formations from the Packerort to Kunda (inclusive of both) (A_2–B_{III}) of Russia are equivalent to the strata from the Dictyonema zone to the Gigas limestone of Scandinavia and to the Canadian (Beekmantown) of America.

Lower Middle Ordovician.

As has already been stated, there is throughout northern Europe, a distinct change in fauna after the deposition of the last of the strata correlated above with the Beekmantown of America.

In Russia, in Västergötland, and on Oeland, where there is a continuous section of calcareous strata this change is less marked than in Norway, where the Gigas limestone is succeeded by black shales, but it is shown as well in Scania where the strata of the section are mostly shales.

In Russia, C_1 marks the introduction of the Echinosphaerites-Christiania fauna, in which nearly all the species are different from those found in the strata below. In Norway, the Gigas limestone is followed by black shales with the *Didymograptus geminus* fauna, and in Scania the shale with *Phyllograptus* cf. *typus* is followed by shale with *Didymograptus geminus*. On Oeland, the Gigas limestone is followed by limestone with *Asaphus platyurus*, and that in turn by limestone with *Illaenus chiron* and *Didymograptus geminus*. Throughout Scandinavia then, the zone with *Didymograptus geminus* is the earliest zone of the series succeeding the Arenig. In Great Britain likewise there is a zone of *Didymograptus murchisoni*, a species practically identical with *D. geminus*, which is considered as the lowest zone of the Llandeilo. In Great Britain there are two species of Dicellograptus in the fauna of this zone, and no species of either Phyllograptus or Tetragraptus are present. The latter statement is true also of Scandinavia, and the zone is known at all localities as being the oldest in which there is a profusion of diplograptids. This zone is not yet positively identified in America. Ruedemann has provisionally correlated the Bed 7 of the Deep Kill section of New York with the European strata containing the *Didymograptus murchisoni* fauna, but although Phyllograptus and Tetragraptus were not found by Ruedemann, the remainder of the fauna is so nearly identical with the fauna of the *Diplograptus dentatus* zone of the Lévis section, where both Tetragraptus and Phyllograptus do occur, that I am inclined to believe that the zone 7 belongs with the Lévis.

In Scandinavia the *Didymograptus geminus* beds are followed by the Lower Dicellograptus shales, containing the zones, in ascending order, of *Glossograptus hincksi*, *Climacograptus putillus*, and *Nemagraptus gracilis*. Unfortunately, a great deal remains to be done before a very satisfactory correlation of the Echinosphaerites limestone of Norway

with the Lower Dicellograptus shale of Sweden can be made. Echinosphaerites has not yet been reported directly associated with a graptolite fauna containing diagnostic species. The shales with the Lower Dicellograptus faunas are found at the north in Jemtland and at the south in Scania, in both of which places Echinosphaerites is absent.

On Oeland, Echinosphaerites occurs at two horizons. The first occurrence is in the Platyurus limestone, in strata below the Chiron limestone, which contains *Didymograptus geminus*. The second appearance is in Chasmops limestone, which is the horizon in which it is found at Kinnekulle and in Västergötland generally.

At Kinnekulle, Echinosphaerites is found in the Chasmops limestone, which is a formation consisting of limestone interstratified with shale, the shale holding undetermined graptolites. Very little seems to be known of the detailed distribution of the faunas in the Chasmops formation in Västergötland but the general consensus of opinion seems to be that the Echinosphaerites is confined to the lower portion. Of the trilobites listed from the Chasmops limestone in Västergötland and Dalecarlia, *Remopleurides sexlineatus*, *Ptychopyge glabrata*, *Ampyx rostratus*, and *Agnostus trinodus* all occur in the zone of *Dicranograptus clingani* in Scania. The zone of *Dicranograptus clingani* is the one next above the zone of *Nemagraptus gracilis*, both in Scania and in Jemtland.

In Gästrikland and Dalecarlia conditions seem to be somewhat similar to those in Russia, for in Delarne the Platyurus limestone contains a layer practically made up of "linsen," and boulders from Gästrikland referred to the Chiron limestone contain "linsen" and such typical Russian species as *Asaphus kowalewski*, *A. cornutus*, and *Christiania oblonga*. In other boulders, said to be lithologically like the Chiron limestone, but referred by Wiman to the Chasmops limestone, *Echinosphaerites aurantium*, and *Christiania oblonga* are found.

In the Christiania district of Norway, as has already been stated, the Gigas limestone is succeeded by black shale and limestone, forty to forty-five meters thick, with *Didymograptus geminus*. Other significant fossils found here are *Asaphus platyurus*, *Ogygiocaris dilatata*, and *Lituites lituus*, fossils found in the Platyurus, Chiron, and Ancistoceras zones at Kinnekulle and on Oeland, leaving no doubt as to the correlation of these strata. Following this zone which is known as 4 $a\alpha$, is the zone 4 $a\beta$, the zone of *Echinosphaerites aurantium*. Here the strata are dark blue to black limestone and dark shale interstratified and the thickness is about fifty meters. The Echinosphaerites are confined to certain layers and various trilobites are present,

among them, *Ogygiocaris dilatata, Nileus armadillo, Trinucleus coscinorrhinus,* all of which are found in the zones of *Climacograptus putillus* and *Nemagraptus gracilis* in Jemtland.

It would seem from the comparison of sections that Echinosphaerites appeared in northern Europe first in Oeland and migrated thence into Norway and Russia. Its occurrence in Oeland in strata older than those containing *Didymograptus geminus* shows definitely that it antedated there the first appearance in Norway, for in the latter country it is found first in strata resting upon those containing *D. geminus.* In Russia the sequence of faunas, Echinosphaerites first and then Echinosphaerites and Christiania, is exactly the same as in Norway, strongly suggesting that the Echinosphaerites did not reach that country sooner than it did Norway. There is physical evidence in Russia of an interruption of sedimentation after the Kunda formation was deposited, while there is but slight evidence of a break between the Reval and the Kuckers. This, coupled with the faunal evidence, particularly the total absence of the Ogygiocaris fauna in Russia, indicates such a correlation as I have shown in the table.

The Ogygiocaris fauna is Norway is found best developed in 4 aα but many of the species pass over into 4 aβ, among them the *Ogygiocaris dilatata* itself. In Jemtland Ogygiocaris is found in the zones of both *Climacograptus putillus* and *Nemagraptus gracilis* and serves to connect the Nemagraptus zone with the first Echinosphaerites zone in Norway (4 aβ).

Normanskill.

The *Didymograptus geminus* fauna has not yet been identified in America, but the *Nemagraptus gracilis* fauna is well known from the Normanskill shale of New York. At the type-locality, however, the Normanskill shale is very much faulted, folded, and twisted, and its correlation with the formations of the standard section is not yet established. Ruedemann at first considered it to be of early to Middle Trenton age but later inclined to correlate it with the Black River. Ulrich (119) has considered it still older, placing it below the Lowville, but above the typical Chazy, making it a member of his Blount group, which he places between the Stones River and the Lowville.

In Virginia typical Lower Dicellograptus faunas (*Nemagraptus gracilis* zone) have been seen in sections where the sequence is normal at two localities, but in neither is the evidence fully established. In looking over material collected by Drs. E. O. Ulrich and George W.

Stose from thin-bedded dark limestone at the Mattheson limestone quarry near Abingdon, Virginia, I found numerous specimens of a Robergia very like *R. micropthalma* and a Telephus like *T. bicuspis.* These trilobites were associated with diplograptid graptolites which Dr. Ulrich assures me are of typical Normanskill species. Such an association is found in the *Climacograptus putillus* zone of the Lower Dicellograptus shale at Anderson, Jemtland, Sweden, and the association is too remarkable a coincidence to indicate anything other than approximate contemporaneity of the two formations. Stose gives the following section at Abingdon.

	Feet.
Sevier shale — Eden fossils in upper and Trenton fossils in lower part.	800
Moccasin limestone. Red limestone with few fossils.	400
Ottosee limestone, with Echinosphaerites.	200
Athens shale. Calcareous shale and dark blue shaly limestone above; dark gray fissile shale below. The fauna mentioned was found in lower part.	500–600
Stones River limestone.	400
Knox dolomite (of Beekmantown age).	

From this section it may be seen that the Normanskill is younger than some part of the Stones River, and considerably older than the Sevier shale, the lower part of which seems to be of Trenton age, though to what part of the Trenton it appertains is not yet evident.

The other section containing the Normanskill fauna was described by Powell (105) and is near Salem, Virginia. He records the following, in descending order: —

		Feet.
	Medina sandstone (Silurian).	
8.	Shale, very fossiliferous. No list of fossils.	1200
7.	Blue to black shale and limestone.	300
6.	Red and gray sandstone without fossils.	400
5.	Blue and black limestone without fossils.	500
4.	Black carbonaceous shale with numerous graptolites. 32 species are listed, including *Nemagraptus gracilis, Climacograptus putillus* and *Dicellograptus sextans. Triarthrus* and *Trinucleus* are also recorded.	560
3.	Coarse grained dark limestone with bands of marble.	250
2.	Pure "dove" colored limestone with a Tetradium and large gastropods.	50
1.	Cherty magnesian limestone with *Maclurites.*	500

Professor Powell was good enough to spend three days in showing the writer this section, and my interpretation of it differs somewhat from that in his published account. The cherty magnesian limestone at the base (zone 1) appears to belong to the Beekmantown, not the Chazy, and Ophiletas were found in the upper beds. Zone 2 is a fine-grained buff limestone with numerous gastropods and some trilobites. At the base is a conglomerate with pebbles of magnesian limestone and chert in a calcareous matrix. This formation is to be correlated with the Mosheim of southwestern Virginia and eastern Tennessee, and that in turn is correlated with the lower part of the Stones River of central Tennessee.

The coarse-grained dark limestone of zone 3 is very fossiliferous, some of the genera present being Hormoceras, Amphilichas, Illaenus, Isotelus, Orthis, Dinorthis, Plaesiomys, Oxoplecia, Leptaena, Plectambonites, and Solenopora, besides numerous bryozoans. This fauna is much more like that of the Black River of New York than it is like any fauna of the Chazy in the typical region, Oxoplecia and Plectambonites in particular being unknown in the Chazy. On the other hand, the fauna is more or less like that of the Holston and Lenoir of eastern Tennessee, and these latter formations seem to be of Middle Chazy age. The relation of this formation to the one below is exactly like the relation of the Leray to the Lowville in New York. The line of separation between the dark, impure limestone above and the pure light-colored limestone below is a sharp one, and yet the top of the one formation and the bottom of the other are combined to form a single layer; a so-called "welded contact."

The Athens shale (zones 4 and 5) is a dark fossiliferous shale in the lower portion, and passes rather gradually into an almost entirely unfossiliferous blue limestone above. *Nemagraptus gracilis* and Didymograptus occur in the lower part of the shale, while Dicellograptus, Climacograptus, and the beautiful synrhabdosomes of Diplograptus are most abundant at about the middle. *Ampyx americanus* appears to begin its range with these latter fossils, being here accompanied by a Triarthrus, and extends up into the limestone of zone 5. In the upper part of its range, I found it accompanied by Cryptolithus, Robergia, and Acrothele. The Athens is plainly equivalent to the Normanskill of New York, and the Lower Dicellograptus shales of Sweden.

Zone 6, the Tellico sandstone, is practically unfossiliferous here as elsewhere. Upon it rests a thick mass of shale with some thin-bedded limestone. This formation is generally called the Sevier in southwestern Virginia, and has not yet been studied in sufficient detail to

permit of exact subdivision or correlation. In this section, the lower 500 feet or thereabouts appear to be of Trenton age, while the remainder of the strata are probably Eden and Maysville, but where to draw the line between the two is not yet fully determined. Professor Powell is engaged upon a further study of the section, and will soon be able to give more detailed information.

The lower 100 feet of the part of the Sevier referred to the Trenton consists chiefly of shale, and its fossils are Calymene, Dalmanella, and Rafinesquina. The next 125 to 150 feet consist of alternations of thin-bedded limestone and shale, the latter predominant. In this zone *Cryptolithus tessellatus* is common, associated with *Ceraurus pleurexanthemus,* Calymene, Sinuites, Plectambonites, and Dalmanella. About 100 feet above this zone, hemispheric bryozoans are common, and with them are *Parastrophia hemiplicata,* Dinorthis, and Sinuites. The Parastrophia is not the pauciplicate form found in the Lower Trenton of New York and Quebec, but like the form in the Middle and Upper Trenton of Ontario. In this same zone Professor Powell found some graptolites which appear to be *Lasiograptus eucharis,* a Middle Trenton and Utica graptolite in New York. The upper 100 feet of the strata here referred to the Trenton consist almost entirely of thin-bedded blue limestone, and at the very top are great numbers of Zygospira, Plectambonites, and Pholidops, while some layers are full of gastropods.

The rocks above the Trenton consist principally of shale, becoming more and more sandy toward the top. In the middle are some massive calcareous strata, and an occasional layer of limestone is met with at various horizons. The whole reminds one very much of the Lorraine of New York, and the fossils emphasize that impression. The upper 100 feet, more or less, belongs to the Bays sandstone, and has the typical fauna, *Platystrophia* (or *Orthorhyncula*) *stevensoni* Grabau, *Byssonychia walkerensis* Grabau, *B. radiata* (Hall), and other pelecypods and brachiopods. This fauna is generally considered to be of Upper Maysville age.

The section, as interpreted above, seems to place the Normanskill definitely as post-Middle Chazy and pre-Trenton, the Athens and the Tellico together occupying the position usually filled by the Upper Chazy and Black River. Since the Normanskill graptolites occur in the lower part of the formation, they would probably be of Upper Chazy age.

ECHINOSPHAERITES AND CHRISTIANIA FAUNAS.

The position of the Echinosphaerites beds in the American Ordovician section can not be said to be definitely established. The knowledge which we have of these beds is due largely to Dr. Ulrich and to Dr. Bassler (98), and by the former of these investigators the fossil is reported as occurring at three horizons, one below and two above the Lowville.

The evidence concerning the younger of these occurrences, in so far as it has been published, may be found in the description by Stose, of the Chambersburg — Mercersburg map-area, and in the Revision of the Palaeozoic Systems by Ulrich. The following section (here rearranged) is given by Stose (118).

		Feet.
10.	Soft yellowish green sandstone with few fossils, said to be of Eden species	1200±
9.	Black carbonaceous shale, with *Climacograptus spinifer*, *Corynoides calicularis*, *Leptobolus insignis*, *Triarthrus becki*, etc., in lower 100 feet.	800±
8.	Shale and thin-bedded limestone with many small fossils, including *Triarthrus becki*, *Cryptolithus tessellatus*, Ampyx, Caryocaris, etc.	150±

All the above strata are referred to the Martinsburg shale.

7.	Calcareous shale and shaly limestone, with *Christiania trentonensis*, *Plectambonites asper*, *P. pisum*, Oxoplecia, *Parastrophia hemiplicata*, etc. Echinosphaerites in the upper ten feet.	150±
6.	Dark gray, largely thin-bedded limestone with *Nidulites favus*, Ampyx, *Plectambonites asper*, etc.	237±
5.	Dark gray limestone in which Echinosphaerites is very common, Ampyx, Receptaculites, Oxoplecia, and brachiopods also common.	60±
4.	Grayish dense thin-bedded limestone with *Tetradium cellulosum*, *Zygospira recurvirostris*, etc.	150±

These limestones above are all grouped as the Chambersburg limestone.

3. Thin-bedded, pure, fine-grained limestone with *Leperditia fabulites.* 275±
2. Massive pure limestone and layers of black chert. *Maclurites magnus, Tetradium syringoporoides, Ampyx halli,* and brachiopods. 200±
1. Massive and thin-bedded pure and magnesian limestone. Beekmantown limestone. 600±

Zones 1 to 3 are correlated with the Stones River.

According to Dr. Ulrich, the section near Chambersburg, Pa., has a "lower Echinosphaerites bed," forty to fifty feet in thickness, resting upon about 150 feet of limestone referred by him to the Lowville (4 of section on preceding page). This Echinosphaerites bed, which lithologically is a very earthy limestone is said by Ulrich (119, p. 322) to be overlain by about 300 feet of hard dark limestone with Nidulites, and that in turn by 270 [1] feet of strata in which thin beds of limestone are interstratified with thick beds of shale. These strata are characterized by Christiania. A few feet below the top is the upper Echinosphaerites zone, and here Christiania is most abundant. The Christiania beds are capped by the Martinsburg shale, which contains Triarthrus, Cryptolithus, and Corynoides.

At Strasburg, Virginia, still according to Ulrich, the lower Echinosphaerites bed rests upon a cherty limestone 100 feet thick, and the Echinosphaerites is accompanied by brachiopods and bryozoans which suggest to him a correlation with the Decorah shale of Minnesota (called Black River by Ulrich). Above this zone are the massive beds with Nidulites, 207 feet thick, followed by a forty foot bed of argillaceous gray limestone and calcareous shale, containing Echinosphaerites (upper zone) and brachiopods, with other fossils characteristic of the Christiania fauna. This bed is followed above by 300 feet of thin-bedded argillaceous light gray limestone and calcareous shale, passing at the top into true shales. This limestone is referred to the Martinsburg, since it has, in shaly beds ten to thirty feet above the base, *Corynoides* cf. *C. gracilis, C. calicularis, Climacograptus spinifer, Leptobolus insignis,* etc.

This manner of occurrence is in striking accord with that in Norway, where Echinosphaerites occurs first in stage 4aβ without Christiania, and then at a higher horizon 4bα with that fossil.

At Bellefonte, Penn., according to observations made by Mr. R. M.

[1] These figures are given on the authority of Ulrich and do not agree with the sections published by Stose.

Field and the writer, a zone of dark limestone, containing such typical Leray (Black River) species as *Columnaria halli* and *Maclurites logani*, is followed by more argillaceous limestone containing Echinosphaerites and a large number of other fossils. Christiania has not yet been found in the Bellefonte section, but this section does definitely show that the Echinosphaerites zone is there younger than the Leray — Black River of New York. As shown by Mr. Field, there is essential agreement between the section at Bellefonte and that at Chambersburg and Strasburg, so that all three of these occurrences of Echinosphaerites may be dated definitely as post-Leray.

According to Ulrich (119), the Kimmswick limestone at Thebes, Illinois, and Cape Girardeau, Missouri, has at the top a bed of crystalline limestone, from five to thirty feet in thickness, which contains Echinosphaerites and Comarocystites, among other fossils. The Kimmswick at this locality can not be definitely placed in the section, except that it is post-Lowville. In the Nashville dome in Tennessee a formation correlated by Ulrich with the Kimmswick and containing Echinosphaerites has been found at Aspen Hill, where it is forty feet thick, and followed by the Hermitage, the Bigby, and the Catheys formations. The contact with the underlying formation is not shown but Ulrich states that there is no doubt that it rests upon the Carters, which is the equivalent of the Leray or Lowville of New York so that it may safely be stated that here again the Echinosphaerites bed is post-Leray. At this locality we have the Echinosphaerites without Christiania, and the zone apparently corresponds to the lower zone at Chambersburg, Strasburg, and Bellefonte. In this case the formation containing the Echinosphaerites is limited above by the Hermitage formation, a formation which can not be correlated with any New York formation, but which corresponds to the Logana of Kentucky and is also found at Bellefonte above the zone of Echinosphaerites. The Hermitage is followed above by the Bigby limestone, which contains a fauna corresponding to that of the Prasopora zone, or Middle Trenton of New York and Ontario. The Kimmswick limestone, and the corresponding Echinosphaerites zone in Pennsylvania and north-central Virginia, may therefore be correlated with some confidence with the lower part of the Trenton of New York.

The other occurrence of Echinosphaerites in the Appalachian region is in the Ottosee formation of southwestern Virginia and eastern Tennessee. Dr. Ulrich believes that the Ottosee is older than the Lowville, and, if this can be shown to be correct, then this zone is older than the two already discussed. A good section showing the

position of the Ottosee in relation to the other formations is that given by Bassler (98) from outcrops on Walker Mountain north of Marion, Smyth Co., Virginia. The strata there named "Holston marble and associated strata" were later named Ottosee by Ulrich.

		Feet.
Sevier shale.		
	Brown to olive and gray shales.	1500
Moccasin limestone.		
	Impure, argillaceous limestone.	300
Ottosee formation.		
	(e) Unfossiliferous drab shales.	40
	(d) Nodular limestone and yellowish to gray shales holding many Bryozoa.	30
	(c) Massive gray and pink marble with numerous Bryozoa, Solenopora and *Stylaraea parva*.	30
	(b) Clayey nodular limestone and shale. Some of the layers are crowded with Receptaculites.	50
	(a) Massive crystalline limestone.	40
Athens shale.		
	Dark to black shale with black slaty limestone at the base. Linguloids and trilobites are abundant at the base.	500±
Stones River formation.		170
Knox dolomite (Beekmantown in age).		

The Stones River of this section is stated by Bassler to contain in its upper part a typical Chazy fauna, though the only species mentioned are *Maclurites magnus* and *Stylaraea parva*.

The trilobites mentioned as occurring in the Athens are not listed, but it is known that this formation in at least two places in Virginia carries the *Nemagraptus gracilis* (Normanskill) fauna. (See p. 234).

From the Ottosee Bassler lists Echinosphaerites, *Batostoma sevieri*, *Scenellopora radiata*, *Diabolocrinus vesperalis*, *Solenopora compacta*, and *Receptaculites biconstrictus*. It is quite true that this fauna is somewhat unlike that of the Echinosphaerites zone in the other localities, but there is nothing in the composition of the fauna itself to indicate that it is older than Black River. *Receptaculites biconstrictus* is similar to the Black River *R. occidentalis*, which occurs with Echinosphaerites at Chambersburg and Bellefonte, Pa., Batostoma is principally a Black River genus, and the other fossils of the Ottosee have a rather indefinite value in correlation.

The Moccasin is a nearly unfossiliferous red limestone of Middle Ordovician age, the only fossils cited being *Plectambonites sericeus* and *Dalmanella testudinaria*.

The Sevier shale is reported to be of Trenton age in its lower part, and Utica and Eden in the upper. From this particular section it is not possible to say more of the age of the Ottosee than that it is older than the Middle Trenton and younger than the Normanskill. In Tennessee, according to Ulrich, (119, p. 556) the Ottosee is to be seen beneath the Lowville. "Although not so thick as at Knoxville, Bulls' Gap and Athens, the Ottosee is yet well and unmistakably developed in the two Ordovician belts between Clinch Mountain and Clinch River in Hawkins and Hancock Counties (Tennessee). In both bands the Holston underlies the Ottosee and over that is the Lowville. The outcrops referred to are located in the Northern third of the Morristown quadrangle.

"In the band lying just north of War Ridge the Holston rests on a very uneven floor of Knox dolomite. It varies from 0 to 120 feet or more. The Ottosee, which overlies it unconformably, is also thin and variable in thickness, the observed variations ranging from 35 to 100 feet. Above the latter, apparently again with a stratigraphic hiatus between them, comes a series of fine-grained, thin-bedded limestone, 400 to possibly 600 feet in thickness, that is correlated with the Lowville. This determination is made chiefly on the basis of fossils, the lower 50 feet containing fine examples of a fasciculated Tetradium, referred provisionally to *T. cellulosum*, and the upper 200 feet *Beatricea gracilis*. This is followed by the typical Moccasin."

The only possible question about these statements must be as to the identification of the Ottosee, no evidence being presented as to the basis of its correlation with the Echinosphaerites-bearing Ottosee of Virginia. Echinosphaerites is, however, reported from eastern Tennessee. A disturbing element in this matter is that *Christiania subquadrata* Hall is reported by Bassler (Bull. 92, U. S. N. M.) as coming from the Ottosee of Blount Co., Tennessee.[1] If the Ottosee is pre-Lowville, then we have three zones with Echinosphaerites. The oldest, found only in southwestern Virginia and eastern Tennessee, may be pre-Lowville and have, locally, Christiania as well as Echinosphaerites. The second is immediately post-Leray-Black River, and contains Echinosphaerites without Christiania. This is found in northern Virginia, eastern and central Pennsylvania, central Tennes-

[1] Dr. Ulrich tells me this should be Lenoir.

see, eastern Missouri, and southern Illinois. The third and last occurrence of Echinosphaerites is in a zone about 300 feet above the strata containing the second occurrence, and in this highest zone Christiania is abundant. This zone is found so far only at Strasburg, Virginia, and near Chambersburg, Pennsylvania. It is correlated with the Trenton of New York.

Pleurograptus linearis has been found in the typical Utica of this country and here as in Europe marks a younger zone than that of *Dicranograptus clingani*. Since, in Sweden, the beginning of the range of *Dicranograptus clingani* is to be correlated with the last appearance of Echinosphaerites, and, in Norway at least, the sedimentary record from the *Didymograptus geminus* beds to the end of the Echinosphaerites beds seems complete, it would seem that we must parallel the Echinosphaerites-Christiania beds of Europe with the Trenton and Black River of America. The Middle and Lower Chazy would be of the age of the *Didymograptus geminus* strata. Since the Jewe and Kegel of Russia, seem to correspond to the zone of *Dicranograptus clingani* and so to the Middle Trenton of America, and since there is no radical change in fauna through the Jewe, Kegel, and Wesenberg more than could be expected of various faunules in a single formation; and since further these formations contain some species found in the Trenton of America, it seems that they most probably are to be correlated with the American Middle and Upper Trenton, but extending probably on into the equivalent of the Eden and perhaps Maysville, though there is evidence of a very considerable break between the Wesenberg and the Lyckholm, which is Richmond:

Middle Ordovician.

In Europe there is no distinct separation of the Lower Middle Ordovician beds from those above, and I have used the above caption merely to separate the discussion of the *Didymograptus geminus* and *Nemagraptus gracilis* faunas from those which follow.

The most complete section is that in Norway where the zone of the first Echinosphaerites is followed by the zones of 4b, characterized by Chasmops and Echinosphaerites. Zone 4bα, a shale with thin layers of limestone, all very dark in color, is characterized especially by Christiania and *Chasmops conicopthalma*. Here one finds also species of Ampyx, Lonchodomas, Remopleurides, Tretaspis, Sphaero-

coryphe, Calymene, Conularia, and Echinosphaerites. The zone is forty to forty-five meters thick about Christiania.

The strata of 4bβ consist of thin-bedded dark blue limestone with shaly partings and the thickness is about twelve meters. Here one finds much the same fauna as in 4bα, but Christiania has disappeared. A Platystrophia of large size, like the *P. lynx* of the Itfer and Jewe was collected from this zone.

4bγ is another zone of much shale and some thin-bedded limestone, with a variable thickness, usually from thirteen to sixteen meters. *Chasmops extensa* is the guide fossil and Brögger has not listed any others. I myself found no fossils worth saving at this horizon.

4bδ, the last of the zones of 4b, consists of interbedded dark blue limestone and almost black shale, the thickness being about twelve to seventeen meters. In this zone are found the last and the largest of the Echinosphaerites, and a very Trenton-like fauna, in which I was interested to note two common American forms, a Parastrophia somewhat like *P. hemiplicata*, and a Triplecia very like *T. nucleа*. *Cyclocrinites spasskii* makes its first appearance in Norway at this horizon, and Illaenus, Ampyx, Trinucleus, Remopleurides, Cybele, Chasmops, etc., are present. Brögger (94) correlates this zone with the Jewe of Russia with which I entirely agree, only adding that the presence of *Cyclocrinites spasskii* suggests also the Kegel. It seems quite possible that there is a break in the sedimentary record in the Christiania district at this point.

In the Christiania area the zone 4bδ is followed by the zone 4cα, the beginning of the *Trinucleus seticornis* fauna, correlated with the Trinucleus shales of Sweden. In the district Mjösen, north of Christiania, however, Holtedahl (97) has found a different succession, and strata which, in my opinion, are to be intercalated between 4bδ and 4cα, and not to be correlated with 4c as Holtedahl has done. As in Christiania, stage 4 in Mjösen is introduced with an Ogygiocaris zone, containing *Ogygiocaris dilatata, Didymograptus geminus* and many other species, this zone having a probable thickness of twenty to thirty meters. This is followed by a thin zone of calcareous shales, three to four meters thick, and it in turn by black shales with limestone nodules, the thickness unknown. The fauna consists very largely of gastropods and cephalopods, of which many species are listed. The fauna is connected with the preceding zones by the presence of *Ogygiocaris dilatata,* but no species pass on into the overlying strata. We have here probably a very unusual development of the strata of the age of the zone of *Nemagraptus gracilis.*

The next formation, B_1 of Holtedahl's section, consists of practically unfossiliferous shales and thin-bedded sandy limestone which passes above into B_2, sandy limestone and shale containing *Coelosphaeridium cyclocrinophilum*. In the upper part of the same formation is a large fauna which includes many species found in the Jewe of Esthonia. *Cybele grewingki* Schmidt, *Chasmops marginata* Schmidt, *Porambonites schmidti* Noetling, *Coelosphaeridium cyclocrinophilum* Roemer and *Mastopora concava* Eichwald are among the striking species which Holtedahl lists as common to the two regions. The thickness of this formation is unknown but it must be over forty meters.

Then follow two very fossiliferous zones both characterized by an abundance of Cyclocrinites, and making a total thickness of about twenty-three meters. These formations have a fauna entirely comparable to that in the Kegel of Esthonia. Holtedahl lists the following species found in both B_3 and the Kegel:—

Basilicus kegelensis Schmidt, *Chasmops maxima* Schmidt, *Chasmops bucculenta* Sjögren, *Pterygometopus kegelensis* Schmidt, *Bucainiella lineata* Koken, *Leptaena* aff. *schmidti* Törnquist, *Platystrophia biforata* Schlotheim, *Triplecia insularis* Eichwald, *Cyclocrinites oelandicus* Stolley, *C. vanhoeffeni* Stolley, and *C. balticus* Stolley.

Holtedahl correlated these latter zones, B_3a and B_3b, with the Trinucleus shales of Sweden, the Trinucleus shales and Isotelus limestone of Norway, and the Kegel and Wesenberg of Esthonia. In regard to the correlation with the Trinucleus shales, Holtedahl himself says that there are only two species, *Illaenus linnarssoni* and *Remopleurides dorsospinifer* common to the two. Neither of these species is a guide fossil, *Illaenus linnarssoni* in particular having a very long geological range. It is worthy of note that none of the Bohemian species which make so important a part of the fauna of the Trinucleus zone of Sweden and the Christiania district is found in B_3 of the section in the Mjösen district, but the fauna is strictly of the Russian type and belongs to another basin. In this case, the difference can hardly be due to difference in facies, for the Trinucleus beds of the Christiania district contain a large amount of limestone; not a sandy limestone, it is true, but neither is the Kegel a sandy limestone. Furthermore, we are not here dealing with graptolites or other fossils highly sensitive to environmental conditions, but with general faunas.

In Jemtland, the Trinucleus shales appear to be absent, and among the boulders of "Oestseekalk" are found many of the characteristic fossils of the Kegel and Wesenberg limestones, indicating that these

formations may in former times have extended across this northern region. In Dalecarlia, however, which is well to the north, the Trinucleus shales are well developed, and contain the typical southern fauna. The Kegel and Wesenberg are certainly older than the Trinucleus shales.

The Chasmops limestone of Sweden has been little studied except for the work of Olin on the trilobites in Scania, and the time is not yet ripe for accurate correlations. The Upper Chasmops or Macrourus limestone of Dalecarlia contains such species as *Chasmops maxima* Schmidt, found in Russia in the Jewe and Kegel, while the lower Chasmops limestone of the same region contains such typical Kuckers and Itfer fossils as *Echinosphaerites aurantium*, *Chasmops odini*, and *Oxoplecia dorsata*. The Chasmops limestone is therefore correlated as indicated by these fossils. As mentioned above, there are certain trilobites which serve to connect the Chasmops limestone with the shales in Scania containing *Dicranograptus clingani* and *Pleurograptus linearis*. Between the zone of *Nemagraptus gracilis* and that of *Dicranograptus clingani*, there is, it seems, a considerable gap, so that the section in Scania is far from complete.

Zone of Dicranograptus clingani.

In southern Sweden the zone of *Nemagraptus gracilis* is succeeded by the zone of *Dicranograptus clingani*, or as it is sometimes called, the Middle Dicellograptus beds.

These beds, have recently been studied in great detail on Bornholm, politically an apanage of Denmark, but geologically in the Scanian province. Hadding (61) has recognized four subzones on this island. These are in descending order:

4 Zone with *Climacograptus styloideus* Lapworth.
3. Zone with *Dicranograptus clingani* Carruthers.
2. Zone with *Amplexograptus vasae* (Tullberg).
1. Zone with *Climacograptus rugosus* Tullberg.

Among the fossils of zone 4 may be mentioned, beside the name fossil, *Glossograptus quadrimucronatus*, *Diplograptus truncatus*, *Dicellograptus pumilis*, *Leptograptus flaccidus macer*, and inarticulate brachiopods.

Zone 3 has a large fauna, including among others, *Amplexograptus vasae*, *Climacograptus brevis*, *Dicellograptus forschammeri*, *D. pumilis*, and *Corynoides curtus*. There are also several inarticulate brachiopods and *Dalmanella argentea*.

In zone 2 the only graptolites are *Amplexograptus vasae* and *Corynoides curtus.*

Zone 1 contains *Climacograptus scharenbergi* and *C. rugosus.*

In America the zone of *Dicranograptus clingani*, though that species itself is not present, is found in the shales of eastern New York and Canada. These shales were long called Utica, but Ruedemann (113 and 117) has shown that they are older and equivalent to the calcareous Trenton of Central New York. The shales are also involved in the mass of the so-called Hudson River shales in the Hudson Valley. They are the Cumberland Head shales of the Champlain Valley, the Snake Hill shales of the Hudson Valley, and the Canajoharie shales of the Mohawk Valley.

At Canajoharie, the type-locality for the formation of that name, Ruedemann (117) found the following sequence of faunas:—

At the base, are seventeen feet of dark blue fossiliferous limestone with interstratified shale beds. This limestone is basal Trenton and contains the Cryptolithus fauna in the limestone, while the interstratified shale afforded *Corynoides calicularis, Diplograptus amplexicaulis,* and *Mesograptus mohawkensis*, so that we here have an indication of the fauna of the shaly equivalent of the Glens Falls limestone.

Above this comes the Canajoharie shale, which is strongly calcareous in its lower portion, becoming truly argillaceous above.

In the lower sixty-five feet of the Canajoharie, *Diplograptus amplexicaulis* is the only graptolite, while in a zone between 65 and 120 feet above the base of the formation, *Corynoides calicularis, Diplograptus putillus,* and *Lasiograptus eucharis* are added. Brachiopods, pelecypods, and crustaceans are fairly common in both zones. In the zone from 115 to 150 feet above the base *Glossograptus quadrimucronatus cornutus* appears, associated with some of the previously mentioned graptolites. These pass up through the next 120 feet, to 270 feet above the base of the formation. *Triarthrus becki* is not noted until a height of 190 feet above the base of the formation, when it appears suddenly in great numbers.

Thus, combining the information obtained from the Canajoharie and Sprakers sections — these localities are only about two and one half miles apart — Ruedemann made out four faunal zones.

4. Zone of *Climacograptus spiniferus, Diplograptus vespertinus,* and *Lasiograptus eucharis.*
3. Zone of *Lasiograptus eucharis, Trocholites ammonius,* etc.
2. Zone of *Glossograptus quadrimucronatus cornutus, Corynoides calicularis,* etc.

1. Zone of *Diplograptus amplexicaulis, Corynoides calicularis*, etc. As one goes further west the limestone at the base of the section becomes thicker and it is found that the graptolites characteristic of the lower part of the shale at Canajoharie are not present, but the lowest of the shale beds, resting on the limestone, contain species which first appear high in the section at Canajoharie.

At Dolgeville, half way between Canajoharie and Utica, where the lower 200 feet of the Trenton is limestone, the first shale bed contains *Glossograptus quadrimucronatus, Climacograptus typicalis*, and *Lasiograptus eucharis*, which is interpreted by Ruedemann as being a fauna younger than that of zone 2 above, since *Climacograptus typicalis* is best developed in the still higher Utica shales.

In the typical Trenton at Trenton Falls, *Diplograptus amplexicaulis* is a rather common graptolite in the lower part of the formation, where it is found in limestone. (See Fig. 1, p. 257).

The typical Utica, or zone of Pleurograptus linearis.

At Holland Patent and South Trenton, New York, where the black shale of the typical Utica rests upon the top of the Trenton limestone not far from the type-locality, the following fauna has been found: —

Callograptus compactus (Walcott),
Climacograptus typicalis Hall,
C. putillus (Hall),
Mastigograptus simplex (Walcott),
M. tenuiramosus (Walcott),
Pleurograptus linearis (Carruthers),
Leptograptus annectans (Walcott),
Dicranograptus nicholsoni Hopkinson,
Glossograptus quadrimucronatus Hall. var.
Lasiograptus eucharis also occurs nearby and in beds a little higher in the section.
L. bimucronatus timidus Ruedemann.

This may be taken as the typical Utica fauna, but it may be remarked that it has not been found in its entirety, at any other locality. Associated with these graptolites one finds also *Triarthrus becki* and *Cryptolithus tessellatus*. It will be noted that in the above fauna there are certain graptolites which are found at a lower horizon, such as *Climacograptus typicalis, Glossograptus quadrimucronatus*, and *Lasiograptus eucharis. Mastigograptus simplex* has until recently been found only at Holland Patent and the immediate vicinity. *Lasiograptus bimucronatus timidus, Leptograptus annectans*, and *Mastigo-*

graptus tenuiramosus, are restricted to that locality and the Fulton of the Cincinnati district. *Pleurograptus linearis*, which is so important a fossil in northern Europe, is in this country known only from a single specimen found at Holland Patent. *Callograptus compactus* is also known only from Holland Patent. There are varieties of *Dicranograptus nicholsoni* in older shales, but the typical form is restricted to the horizon of the Utica of Holland Patent. It is found also in the Fulton shale of the Cincinnati district and near Saratoga. In attempting a correlation of any other fauna with that of the typical Utica it must be borne in mind that some of the typical species of that fauna are so rare that but few specimens are known. Practically all the species of graptolites which are not restricted to the locality at Holland Patent are species of considerable vertical range. The occurrence, however, of *Pleurograptus linearis* stamps that fauna as younger than that with *Dicranograptus clingani* and probably equivalent to the upper Chasmops shale of Sweden.

The Fulton shale at the base of the Eden at Cincinnati contains a graptolite fauna very like that at Holland Patent. Some of the species are: —

Mastigograptus tenuiramosus (Walcott),
Leptograptus annectans Walcott,
Dicranograptus nicholsoni Hopkinson,
Climacograptus typicalis Hall,
C. putillus (Hall),
Lasiograptus bimucronatus timidus Ruedemann.

Associated with these are *Cryptolithus tessellatus* and *Triarthrus becki*. In higher beds of the Eden of the same region one finds *Dictyonema arbuscula* Ulrich, *Mastigograptus gracillimus* (Lesquereux), *Chaunograptus gemmatus* Ruedemann, and *Climacograptus typicalis* Hall.

From the above we may derive that the more widespread species of the typical Utica (*Pleurograptus linearis* fauna) are *Mastigograptus tenuiramosus*, *Leptograptus annectans*, *Lasiograptus bimucronatus timidus*, and *Cryptolithus tessellatus*. *Climacograptus typicalis*, *Dicranograptus nicholsoni*, and *Triarthrus becki* are also species which though not strictly restricted to the Utica, are to be found in every outcrop of that formation.

From the above it is evident that while some of the graptolites have a long range in the black shales of New York, there are species which seem to be characteristic of certain horizons. Thus we have in the

shale equivalent of the Lower Trenton, *Corynoides calicularis* and *Diplograptus amplexicaulis,* in the shale equivalent of the remainder of the Trenton (as exhibited in the Trenton Falls section) *Lasiograptus eucharis, Glossograptus quadrimucronatus* var., *Climacograptus putillus,* etc., and in the shale above the Trenton of Trenton Falls, *Leptograptus annectans* and the other fossils listed above.

If we now return to the Lower Mohawk Valley, we find above the Canajoharie shale the Schenectady formation, composed largely of sandy shale and sandstone, but containing some graptolites and other fossils. Our knowledge of this fauna is due almost entirely to Dr. Ruedemann. That author has correlated the Schenectady with the Upper Trenton, but, to my mind, on very inadequate evidence. Some of the more important fossils of the formation are:—

Azygograptus sp.
Mastigograptus cf. *M. simplex* Walcott.
Diplograptus vespertinus Ruedemann.
Climacograptus bicornis ultimus Ruedemann.
C. typicalis Hall.
Lasiograptus eucharis Hall.
Rafinesquina ulrichi James.
Trocholites ammonius Conrad.
Triarthrus becki Green.
Cryptolithus tessellatus Green.

and numerous eurypterids.

Ruedemann states that this fauna bears a Utica aspect, but that the graptolites point as much toward the Canajoharie fauna as toward the typical Utica. In this connection we must note the absence of *Diplograptus amplexicaulis, Corynoides calicularis,* and *Glossograptus quadrimucronatus.* It is true that none of the graptolites listed are confined to the Utica of the Holland Patent type, but both *Climacograptus typicalis* and *Lasiograptus eucharis* are very abundant in the typical Utica. The presence of a Mastigograptus comparable to *M. simplex* also suggests Utica, as does the presence of Eurypterida. Finally, and most important, is the presence of *Cryptolithus tessellatus,* a fossil which to Dr. Ruedemann suggested the Trenton age.

The geological range of *Cryptolithus tessellatus* seems to be quite generally misapprehended. It is frequently thought of as a fossil which occurs almost anywhere in the Trenton, whereas, as a matter of fact, it is restricted to certain definite horizons and is not everywhere present.

The earliest appearance of Cryptolithus in New York is very near the base of the Trenton, where it is exceedingly abundant in the Glens Falls formation. At this horizon it is very abundant near Quebec, at Montreal, in the Champlain Valley, and the Mohawk

Valley, in all of which places it occupies a thin formation, its vertical range never exceeding forty feet. A very few specimens have been found in the lowest layers at Trenton Falls, but it is absent from more northern outcrops of the Trenton. It is not found in the Trenton anywhere in the region of New York west of the Adirondacks, it is absent from the Trenton of Ontario and Quebec west of Montreal, and it is absent from Minnesota. The second occurrence in New York is not in the Trenton, but in the typical Utica, at Rome and the vicinity. It occurs also in the Frankfort, and still higher, in the Pulaski.

In the vicinity of Quebec the second appearance of Cryptolithus is in the light-colored sandy shale about 400 feet above the top of the limestone of the Trenton, and above the dark "Utica" shale.

At Bellefonte, Penn., the earliest appearance of *Cryptolithus tessellatus* is, as in New York, just above the limestone containing the Leray fauna, and it reappears in the upper fifty feet of the 600 foot Trenton section, at the point where the limestone begins to pass over into shale, and just before the first appearance of *Triarthrus becki*. In Kentucky, Cryptolithus appears first in the Logana (Hermitage), only a few feet above the base of the Trenton, and does not reappear till the Cynthiana, just at the top of the Trenton or base of the Eden. On the Ohio River at Cincinnati it is in the Cynthiana, and the Lower Eden, and appears again in the Maysville.

The occurrences are so exceedingly alike, and there is so great an indifference displayed as to the character of the sediments, that I am inclined to look upon Cryptolithus as an exceedingly good horizon marker. If this be the case, then the Schenectady formation is to be correlated with the Utica, and, probably, the Frankfort.

CORRELATION OF THE TRENTON IN AMERICA.

One great obstacle to any correlation of the kind attempted in this study is the fact that we have as yet reached no satisfactory solution to the problems presented by our American Ordovician strata. By far the best correlation tables for the Ordovician are those recently presented by Drs. Ulrich and Bassler. My own differs radically from theirs, and I am therefore compelled to traverse the principal outlines of the subject in justification of the departures which I have made from former schemes.

It is only some twenty years since it became known that there is in the United States more than one kind of "Trenton." Naturally, the history of the attempts to correlate the various kinds of "Trenton" has been made in that time. The most troublesome of the still unsolved problems is the exact relation of the "Trenton" (Rysedorph, Chambersburg, Quebec City, Chickamauga, Sevier, etc.) of the Appalachians to the "Trenton" (typical Trenton of New York, Trenton of Ontario, Minnesota, etc.) of the interior.

The Appalachian Trenton, if I may so call it, extends from the destroyed end of the range at Gaspé in intermittent aligned exposures as far as Georgia. A beginning on the description of its fauna was made by Ruedemann (114) in his paper on the fossils in the pebbles of the Rysedorph conglomerate, but practically nothing more has been done along that line. Until the fauna is described the problem will remain unsolved. We have, however, some inkling of what the fauna is like, and notice that while in general similar to the Trenton faunas of the interior, it differs in containing Echinosphaerites, Christiania, Nidulites, Tretaspis, and Lonchodomas in abundance, these genera being unknown in the interior Trenton. Many undescribed forms are also peculiar to this Appalachian area, but the above familiar genera are sufficiently striking. An entering wedge in the solution of the problem has been driven home by the demonstration that the principal zone of Echinosphaerites is, over wide areas, resting upon the Leray-Black River. Here there is then a point of contact between the Appalachian and interior provinces. Dr. Ulrich will agree to this, but will include practically all of the limestone at Chambersburg, for instance, with the Nidulites, Christiania, and Upper Echinosphaerites zones, in the Black River. To show that they represent the Trenton is a difficult, perhaps at present, impossible task, but I shall endeavor to present my reasons for so regarding them. To do this, I must start with the section in New York and proceed by a roundabout western route to reach eastern Pennyslvania.

Trenton in New York.

The type-locality is in New York State, at Trenton Falls. The section at Trenton Falls is unsatisfactory, in that the formation is not there exposed to a low enough level to show the formation upon which the Trenton rests. But a few miles east of Trenton Falls, at Rathbone Brook, is another section which supplements the one at

Trenton Falls, and zones 2 and 1 of the section below are to be understood to be exposed only in small part at Trenton Falls, but completely at Rathbone Brook. The Utica is likewise not exposed directly at Trenton Chasm, but at several places in the immediate vicinity.

Composite section (Raymond, 112). Zones 7 to 3 and upper part of 2 exposed at Trenton Falls.

		Feet.
8.	Thin-bedded black and brown carbonaceous shale with *Triarthrus beeki, Cryptolithus tessellatus, Pleurograptus linearis* and many other graptolites. The contact with the limestone below is sharply defined and there are no transition beds. Utica shale (typical). Thickness about 300 feet.	
7.	Light gray, coarse-grained lithified coquina in thick beds. *Rafinesquina deltoidea, Hormotoma trentonensis* and other fossils.	26
6.	Thin-bedded blue limestone with shaly partings. *Rafinesquina deltoidea* the common characteristic fossil.	92
5.	Thin-bedded blue limestone with thick shaly partings. *Prasopora simulatrix* and other common Trenton fossils abundant.	100
4.	Thin- and thick-bedded limestone, dark in color and fine-grained. *Diplograptus amplexicaulis* a common fossil.	35
3.	Thin-bedded dark limestone with *Triplecia extans* and other fossils.	20
2.	Thin-bedded dark limestone with some inter-bedded coarse-grained layers. *Cryptolithus tessellatus* the characteristic fossil. *Trematis terminalis, Platystrophia trentonensis, Calymene senaria* and many other fossils present.	41
1.	Thin-bedded gray limestone with an abundance of *Dalmanella rogata,* and some other fossils.	32

The Leray-Black River is beneath 1. I wish to call especial attention to the fact that there are here two zones of *Cryptolithus tessellatus;* one in the forty-one feet of limestone near the base of the section (this is the Glens Falls limestone) and one in the Utica shale. *Cryptolithus tessellatus* is not a facies fossil, as its occurrence in this section shows for it is in both dense fine-grained blue limestone and coarsely crystalline gray limestone (coquina rock) in the lower zone, and in the Utica it is in a very fine-grained carbonaceous shale. In northern New York at the eastern end of Lake Ontario, it is found in

green, yellow, and brown sandy and calcareous shale, and in sandstone in the Lorraine (Pulaski).

When the Trenton is traced northward from Trenton Falls it is found well exposed along the tributaries entering the Black River from the west. In this region the Cryptolithus bed is no longer seen at the base of the formation, but the middle beds with *Prasopora simulatrix* are the same as at Trenton Falls. At the top, however, a considerable thickness of strata are added, of a kind not seen at Trenton Falls, and containing a fauna not found there. Above thin-bedded limestone containing *Rafinisquina deltoidea*, these beds being the equivalent of the upper strata at Trenton Falls, one finds thick-bedded impure dark gray limestone which on weathering breaks down into a rubbly mass. This limestone contains many gastropods and some other fossils, the most characteristic being *Hormotoma trentonensis*, *Fusispira subfusiformis*, and *Cyclospira bisulcata*.

It is interesting to note that the species which are most characteristic of the upper beds and most of which are not found at Trenton Falls, were described originally from this region. Thus the type-localities of *Fusispira subfusiformis* are Adams, Jefferson County, where only these upper beds are exposed, and Turin, Lewis County. *Trochonema ambigua*, *Fusispira vittata*, and *Cyclospira bisulcata* were all described from specimens obtained at Adams, and *Holopea paludiniformis* and *Subulites elongatus* were both found originally in the higher Trenton strata at Watertown. Of all these species, only the last has been found at Trenton Falls, and in New York they are characteristic of strata above the strata exposed at Trenton Falls, and the highest Trenton limestone exposed in the State.

Ontario.

Crossing into Ontario, the section is practically identical with that in northern New York, except for certain local developments. The strata in the middle of the Trenton remain the same as those at Trenton Falls, but the lower beds do not carry Cryptolithus. The lower beds do, however, show a decided recurrence of Black River conditions and faunas, as high as 100 feet above the base of the formation, so that there is here practically continuous sedimentation after the Leray, the Trenton fauna gradually replacing the Leray fauna. In this respect the section reminds one greatly of Kentucky, as will be seen later.

The section, in descending order, is as follows, the section at Ottawa being taken as typical of the region.

		Feet.
6.	Dark brown to black carbonaceous shale with *Triarthrus spinosus*, *T. becki*, *T. glaber*, *Leptograptus annectans*, *Glossograptus quadrimucronatus*, and other graptolites. Gloucester formation. (New Name).	50–75
5.	Interstratified limestone and dark shale. Characteristic fossils are *Ogygites canadensis*, *Oxoplecia calhouni*, *Zygospira uphami*, *Plectambonites rugosus*, etc. Collingwood formation.	25–30
4.	Thick-bedded dark gray limestone with very little shale. Characteristic fossils are *Fusispira subfusiformis*, *F. nobilis*, and many other gastropods, *Cyclospira bisulcata*, *Strophomena trilobata*, and, in the lower part, *Rafinesquina deltoidea*. Picton formation.	100
3.	Gray limestone, thin-bedded and with much interstratified shale in the lower twenty-five feet, less shaly but not very thick-bedded above. "Prasopora beds" or true Trenton. In the shale at the base *Clitambonites americanus* is the guide fossil, though many others are present. In the strata a short distance above these a profusion of echinoderms are found, among them being *Pleurocystites squamosus*, *P. filitextus*, *Agelacrinites inconditus*, and *Comarocystites punctatus*. *Prasopora simulatrix* is so very abundant throughout these strata that I have usually spoken of them as the Prasopora beds.	100
2.	Coarse-grained light gray thick-bedded limestone, thirty-three feet in thickness, resting upon sixty-six feet of blue to gray fine- to coarse-grained limestone containing great quantities of black chert in layers and flattened cakes. The upper beds contain an abundance of Stromatocerium and Solenopora and in a nearby locality, *Tetradium racemosum*. The lower beds have shaly partings in which great numbers of fine echinoderms have been found, particularly crinoids. Among the characteristic fossils are *Edrioaster bigsbyi* and *Cleiocrinus regius*. Hull formation.	100
1.	Thick-bedded dark gray limestone with partings of shaly limestone containing numerous fossils, among them *Triplecia extans*, *Phragmolites compressus*, *Orthis disparalis*, *Strophomena filitexta*, and *Receptaculites occidentalis*. This formation is not well exposed at Ottawa. Rockland formation.	35

It will be noted that in this section there is a formation added at the top which is even younger than any found in New York and that it is characterized by a fauna differing in a considerable number of species from the fauna found below. The strata containing this fauna are at the base, limestone, but above pass over into dark shale which becomes finally typically "Utica" in facies. The transition from the limestone of the Picton into the limestone of the Collingwood is gradual and some of the species of the Picton continue into the Collingwood; there is probably no break in sedimentation.

Minnesota.

These formations, or at least most of them, can be traced across Ontario to the westward and in Minnesota the following section may be seen (Winchell and Ulrich, 121).

		Feet.
8.	Massive dolomitic limestone with Maclurites and Maclurina. Stewartville dolomite.	50
7.	Fine grained to subcrystalline limestone with some argillaceous layers in the upper portion. Among the fossils are *Rafinesquina deltoidea, Zygospira uphami, Fusispira nobilis, Fusispira inflata, Cyclospira bisulcata,* etc.	56
6.	Cherty limestone with *Orthis tricenaria, Clitambonites americanus, Parastrophia hemiplicata,* etc. Clitambonites bed.	9
5.	Mostly thin-bedded limestone, argillaceous in the lower portion and becoming more pure toward the top.	36
	Zones 7 to 5 belong to the Prosser limestone.	
4.	Blue shales with branching sponges. Fucoid bed.	6
3.	Blue shales with Bryozoa and Ostracoda. Phylloporina beds.	14
2.	Shales with limonite, sometimes oölitic in structure. Many Pelecypoda. Ctenodonta bed.	9
1.	Dark green soft shale with numerous Bryozoa. Rhinidictya bed.	23
	Zones 4 to 1 make up the Decorah shale.	

There are two subdivisions of the Trenton strata in Minnesota which may be correlated directly with formations in Ontario. These are the upper strata of the Prosser limestone, (zone 7 of the section

above), and the Clitambonites bed (zone 6). The zone 7, with its large gastropods, particularly the Fusispiras and Trochonemas, *Cyclospira bisulcata, Rafinesquina deltoidea,* and *Strophomena trilobata,* is an exact counterpart of the Picton of Ontario.

The Clitambonites beds of both Ontario and Minnesota are characterized by the same species of Clitambonites and Parastrophia, and there are many more fossils common to the two.

The Decorah shales of Minnesota have been correlated by Dr. Ulrich with the strata above the Leray-Black River and below the cystid beds at Kirkfield, Ontario, and on this point we are in agreement.

The Stewartville dolomite is not present in Ontario, nor have any

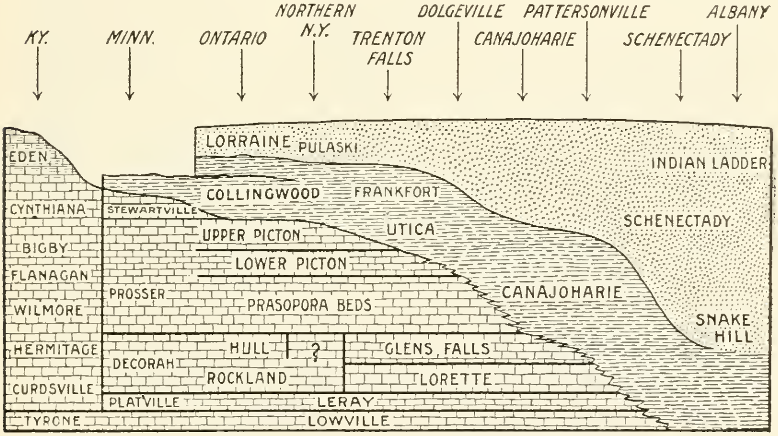

Fig. 1.— Correlation of the sandy and shaly strata of eastern New York with the calcareous strata of the more western localities. The strata represented by the dots are predominantly sandy shales and sandstones, with subordinate amounts of black shale. The next beds below are very fine-grained shales, usually very dark in color, and the remaining strata, represented by the "brick" design, are principally limestone. For Plat'ville, read Platteville.

of its characteristic fossils been found there. In Minnesota a part of the Prosser fauna passes over into the Stewartville, and there does not appear to have been any break in the sedimentary record, so that there was apparently here a persistence of limestone deposition after it had ceased in Ontario.

Reviewing what has been said of the preceding sections, it will be seen how the shales in their westward progress transgressed higher and

higher beds of the Trenton series and how, as time went on, their own faunal content became changed, showing that it was not a sudden migration of the sea over a tilted and partially eroded series of earlier deposits, but that the near shore black shales were able constantly to encroach upon the portion of the sea where limestone was forming till it finally progressed over the entire northern and eastern portion of the sea.

If we now turn to the south, we find that in Kentucky and Tennessee, clear water conditions prevailed throughout the Trenton and consequently there were very different faunas, a fact best expressed in the presence there throughout the Trenton of the corals Columnaria and Tetradium.

Kentucky.

The following is a section in central Kentucky, after Foerste (102).

		Feet.
7.	Granular limestone above, argillaceous limestone and clay below. This formation is referred to the Eden by the Kentucky geologists. Along the Ohio River opposite Cincinnati it contains Cryptolithus in abundance and in northern central Kentucky it contains a fauna very closely allied to that of the Eden and Maysville. Cynthiana formation.	40
6.	Granular limestone in the upper five feet, nine feet of dense white limestone below, and twenty to twenty-five feet of fine-grained grayish limestone at the base. The fauna is large, containing many gastropods and pelecypods, several brachiopods, and two species of Tetradium, *T. columnare* and *T. fibratum*. Perrysville formation.	35
5.	Granular limestone above, with seven to ten feet of fine-grained argillaceous limestone below. *Columnaria alveolata* is present in the upper part, and the lower bed is the one from which the Brachiospongia have been obtained. It contains the oldest Platystrophia and Clitambonites found in the Kentucky section. Flanagan formation.	60–70
4.	Granular limestone with Stromatocerium. Benson formation.	35
3.	Argillaceous limestone with interbedded thin clayey layers. *Prasopora simulatrix*, *Rhynchotrema increbescens*, and *Hebertella frankfortensis* appear first at this	

horizon, most of them passing up through the Perrysville. Three species of Fusispira, and other gastropods are present. Wilmore formation. 70

2. Fine-grained limestone alternating with clayey layers of similar thickness. *Heterorthis clytie, Dalmanella fertilis, Leptaena tenuistriata,* and *Cryptolithus tessellatus* are characteristic species. Hermitage formation. 22
1. Granular limestone with cystids, *Edrioaster bigsbyi, Orthis tricenaria, Dinorthis pectinella,* etc. Curdsville formation. 23

On a first survey of the lithological characteristics of the section in central Kentucky, one is impressed by the large amount of light-colored, fine-grained and coarse-grained rather pure limestone and the lack of dark-colored shale.

Columnaria occurs in the Curdsville, Flanagan, and Cynthiana formations, and Tetradium in the Hermitage, Perrysville, and Cynthiana, so that the Wilmore and Benson are the only formations without corals.

Because of the presence of species of Amygdalocystites, Pleurocystites, and Edrioaster in the Curdsville in Kentucky it has become the custom to correlate this zone with the cystid zone of Ontario. Ulrich, and following him, Bassler, have correlated the Prosser of Minnesota with the Curdsville of Kentucky, a correlation not borne out, I think, by the evidence.

The Curdsville fauna of Kentucky is a pure derivative of the Black River, only the echinoderm fauna being added to a rather typical Leray-Black River assemblage of fossils.

In Minnesota the Pleurocystites occur in a very different association. They are found in the lower part of the Fusispira beds (zone 7 of the section above) where they are associated with *Strophomena trilobata, Cyclospira bisulcata,* and *Rafinesquina deltoidea,* all Upper Trenton species in New York and species which are never found so low as the Black River. This zone is also above the Clitambonites bed, which can not be correlated with anything older than the Wilmore of Kentucky.

In Ontario there are three "Curdsville" zones, two above and one below the bed which is correlated with the Clitambonites bed of Minnesota. All are seen in the section at Ottawa, where the zones are separated by seventy-five feet of strata containing two distinct faunules.

The lower zone, to which I have given the formation name Hull, is

well exposed at Kirkfield, which locality has become famous for its beautiful crinoids, cystids, and starfishes. Though separated at this locality by about twenty-five feet of strata (Rockland formation) containing a good fauna in which a number of Trenton genera are introduced (Platystrophia, Triplecia, Calymene, etc.), the Hull contains a number of fossils which have survived from the Black River. It is very near the horizon of the Curdsville. At Ottawa this formation contains many echinoderms but very few Pleurocystites, these fossils being abundant in a zone seventy-five feet higher in the section. It was from these higher beds that *Pleurocystites squamosus* and the other species described by Billings were obtained. From this upper bed all the Black River species are absent and the cystids are associated with species of the Clitambonites fauna. In this same section at Ottawa there is a third zone of echinoderms, some forty feet above the middle one, and in the Picton formation. This zone has produced a number of cystids and blastoids associated with *Strophomena trilobata, Rafinesquina deltoidea,* and *Cyclospira bisulcata,* and though, so far as I know, no Pleurocystites have been found at this horizon, it is probably the horizon with which the Minnesota cystid bed is to be correlated. In other words, in the Ottawa section there is a lower, a middle, and an upper Trenton Curdsville bed, no one of which is exactly of the age of the Curdsville bed of Kentucky, and affording plain evidence that the echinoderms in themselves are of no value in determining correlations. From a study of the associates of the fossils it is very evident that the Curdsville of Kentucky is most nearly of the same age as the Hull of Ontario, whence it follows that the higher beds in Ontario are younger. The Minnesota "Curdsville" is youngest of all, and to be correlated with the Picton of Ottawa and northern New York, and that is in turn younger than the strata exposed at Trenton Falls. If on the other hand, the Curdsville of Kentucky is to be correlated with the "Curdsville" of Minnesota, then the base of the Kentucky section is above anything seen at Trenton Falls, and not below it.

Pleurocystites also appears in eastern New York and at Montreal, this time in the Glens Falls formation, near the base of the Trenton. These strata are probably of about the same age as the Hull beds of Ontario and the Curdsville of Kentucky though no strict comparison of the faunas is possible.

The second point to be considered in the correlation of the Minnesota and Kentucky sections is the disposition to be made of the group of Fusispiras so characteristic of the Fusispira bed.

Ulrich has said of this fauna: "East of Minnesota we find it well developed, though perhaps occupying only a few inches of limestone, at the base of the Trenton in Northern Michigan, Ontario, Quebec, New York and Northern New Jersey. In the Mohawk Valley in New York, the bed containing this fauna is very thin and only locally present." (119, p. 369.)

The Fusispira fauna in Minnesota is characterized especially by large gastropods, including *Fusispira nobilis, F. inflata, F. ventricosa, F. subfusiformis, F. vittata,* and *Hormotoma trentonensis* and with them are associated *Cyclospira bisulcata, Rafinesquina deltoidea, Strophomena trilobata* and other fossils, though the brachiopods mentioned seem to be found principally just below the real Fusispira zone. In Ontario one finds exactly the same association, at Ottawa, at Picton, Wellington and other places in southern Ontario and at Collingwood on Lake Huron. As I have already pointed out above, this fauna is found in northern New York also at the top of the Trenton, and in sections where one can see the whole Trenton from base to top, as for instance on Roaring Run, south of Watertown, it is clearly seen that the Fusispira beds occupy a considerable thickness, not a few inches, at the top of the Trenton. I have already pointed out above that the typical localities for such of the above species of the Fusispira fauna as were described by Hall are all in the Upper Trenton.

The Fusispira fauna is, in part, so far as relates to its gastropods at least, a recurrent fauna, which fact has not been recognized by Ulrich, and has led to the erroneous correlation of the Minnesotan with other sections. In Minnesota Fusispiras make their first appearance in the Upper Trenton, but in other regions they were introduced with the Black River fauna and recurred at various times. Thus in Kentucky one finds in the Wilmore, *Fusispira subfusiformis, F. angusta,* and *F. angusta subplana,* but its associated fauna contains none of the "guide fossils" found with the Fusispiras in Minnesota. There is a large gastropod fauna, but it is not *the* Fusispira fauna.

In the quotation from Ulrich above, the Fusispira fauna is said to be at the base of the Trenton in northern Michigan, Ontario, Quebec, New York and northern New Jersey. Of northern Michigan I know nothing. Ontario has already been sufficiently discussed. Where in Quebec the Fusispira fauna is developed I can not imagine, though I have an intimate knowledge of the principal localities for the Trenton of that province. In reply to a request for information, Dr. Ulrich wrote me under date of 12 January, 1912, as follows: "The Fusispira fauna was found in New York in the vicinity of Poland, Herkimer

County. Also in the neighborhood of Amsterdam. I have better collections from near Lake Ontario, on Sandy Creek, near Ellisburgh, Jefferson County."

Since receiving this letter I have visited all these localities, the first two of which were already familiar to me from previous work. There can be no doubt that the last locality contains the typical Fusispira fauna, for the strata there are of the very highest Trenton, just beneath the Utica shale, and it is in the immediate vicinity of the places from which the principal species of the Fusispira fauna were originally described. The other two localities are located where only basal Trenton strata are exposed. "The vicinity of Poland" probably means the exposures between Poland and Newport, the localities of the well-known Rathbone Brook section and the "Moshier quarry" in the Leray-Black River. The lower part of the Trenton (Cryptolithus beds) in this section contains some layers with gastropods, but I have found Fusispira here only in the Leray-Black River where it is associated with a number of other gastropods in a large fauna (107).

At Amsterdam the section is practically the same as at Poland. Only the lower part of the Trenton is exposed, and it rests upon a very small thickness of the Leray-Black River, which formation is not very fossiliferous. If any members of the Fusispira fauna are found here, they must be in a very different association from that in Minnesota, and are certainly at a much lower horizon.

The last place mentioned by Ulrich, is in New Jersey, at Jacksonburg, where the formations present are equivalent to those at Amsterdam and Poland in New York and the same remarks will apply to it. Personally I am unable to see in the faunas of any of these localities anything to suggest the Fusispira fauna of Minnesota and even if the Fusispira fauna be there, the section in New York affords ample proof that the Lower Trenton beds with Cryptolithus are below the typical Trenton of Trenton Falls and the Fusispira fauna occurs in the Upper Trenton beds, above the typical Trenton of the Trenton Falls section.

The above discussion is necessary to justify my position in placing the Prosser very much higher in the section than it is placed by other writers.

Central Pennsylvania.

The section in central Pennsylvania at Bellefonte has been described in outline by Professor Collie (100), and has lately been reinvestigated at my suggestion by Mr. R. M. Field, in whose company I was able

to spend a few days on the work. The study of the collections is still incomplete, and considerable field-work remains to be done before any satisfactory correlation can be made, but the preliminary results seem to indicate a correlation with the formations in Kentucky rather than with those in New York. The important fact, mentioned before, of the identification of the fauna of the Leray-Black River in the strata just above the pure quarry rock gives a datum plane for correlation. Above this zone, but still in the strata called "Black River" by Collie, is found the fauna with Echinosphaerites, and in the lowest "Trenton" (A 8 of Collie), one finds fossils such as *Cryptolithus tessellatus, Orthis tricenaria,* Dinorthis, and others which suggest the Hermitage of Kentucky. The "Trenton" has a thickness of 600 feet, and at the top, Cryptolithus comes in a second time, as in the Cynthiana of Kentucky. In our present state of knowledge, it must be confessed that the thickness of the section, the general likeness of the faunas, and the two occurrences of Cryptolithus, are the principal bases on which the correlation is made. So far the upper Echinosphaerites zone with Christiania has not been found at Bellefonte, but the general similarities of the sections at Chambersburg and Bellefonte are such that we fully expect work in the intervening areas to establish a fairly secure correlation between them.

GENERAL DISCUSSION OF RUSSIAN EARLY ORDOVICIAN FAUNAS.

The correlations attempted above have been based largely upon stratigraphic position and "guide fossils." It remains to compare in a little more detail the faunas of the strata which have been correlated.

Walchow and Kunda formations.

The part of the correlation which I must most justify to American students is, probably, that in which I agree with most Continental authors, in assigning the Walchow and Kunda formations, B_{II} and B_{III}, to the horizon of the American Beekmantown. Therefore, I wish, in addition to what has already been brought out, to discuss the faunas of these two formations in some detail. Bassler has correlated the two formations, in a general way, with the lower part of the Black

River, and it has been by no means unusual, even among European text-book writers, to consider the upper formation (Orthoceras limestone) as of Black River age, this being primarily due to the abundance of large cephalopods and of trilobites in both the Orthoceras limestone and the Black River limestone. Bassler's argument seems to be based largely upon the state of development rather than on identity of species of the bryozoan fauna, for of eleven species in the Glauconite limestone and fourteen in the Orthoceras limestone, only two in each are identified by him with American species.

Lamansky has listed 142 species and varieties of fossils from these two formations, and Schmidt and Bassler have since added enough more to bring the number to about 186. Of these, seventy-seven are trilobites, forty-five brachiopods, nineteen cystids, twenty-six bryozoans, eleven cephalopods, four pteropods, and four gastropods.

Trilobites.

Eighteen genera of trilobites are listed, and of these, most of the prominent ones, namely, Asaphus, Onchometopus,[1] Niobe, Pseudasaphus, Ptychopyge, Cyrtometopus, Cybele, Pliomera, and Platopolichas, do not occur in America. Of the remaining nine genera, Nileus and Eoharpes are found in the typical Beekmantown, Megalaspis may occur in the Beekmantown, provided the few American species which have been referred to that genus really belong,[2] and Illaenus is common in the Beekmantown, while the other genera, Ceraurus, Remopleurides, Lichas, Pterygometopus and Ampyx make their first appearance in American faunas in the Chazy or later formations. To these five genera belong eighteen species, mostly rare trilobites, and of the eighteen species, eight are confined to the upper of the two formations.

These figures indicate very clearly the total unlikeness of the trilobite faunas of the Beekmantown of America and the Walchow and Kunda of Russia. Of eighteen genera only four are common to the two, nine are entirely unknown in America, and four make their first American appearance in the Chazy. In America, Lichas appears first in the Silurian.

[1] The American species referred to this genus by the writer must probably be included with Brachyaspis.

[2] *Megalaspis beckeri* Slocum is almost certainly not a Megalaspis.

Brachiopoda.

The Brachiopoda are listed by Lamansky under twelve generic names, but here comparisons are less satisfactory as the species have not been studied critically. Orthis as used in this list includes Orthis *s. s.*, and Dalmanella, and should include Platystrophia, two species of which occur, but are not listed by Lamansky. Acritis should also be added. This increases the list to fifteen genera, two of which we may at once drop, Leptaena as being meaningless in the present state of our knowledge of the three species referred to it, and Lingula as being cosmopolitan. Of the thirteen genera then remaining, eight, Porambonites, Lycophoria, Plectella, Pseudocrania, Acritis, Pseudometoptoma, Philhedra, and Siphonotreta, are unknown in the Ordovician of America. Orthis is known from the American Beekmantown, Dalmanella is probably there, though doubts have been cast on some of the species so referred, and Strophomena may be there, but the reported cases are questioned. Clitambonites appears first in the Chazy, and Platystrophia in the Trenton. In passing, it may be said that *Orthis obtusa* Pander, which is very abundant, belongs to an undescribed genus, unknown in America, and that *Orthis parva* Pander, which Wysogorski (57) states can not be a Dalmanella because impunctate, is in reality exceedingly punctate. Orthis is very common and exceedingly variable in these deposits, but all the species agree in having a much lower cardinal area and a much wider delthyrium than the species which we in America know as a typical Orthis (p. ex. *Orthis tricenaria*). *Orthis panderiana* Hall and Clarke, of our Beekmantown, is much more like the typical Orthis of the Walchow.

Bryozoans.

As previously stated, Bassler describes twenty-six species and varieties from these two formations, four species and one variety being identified as common to Russian and American deposits. *Arthroclema armatum* is said to be common to the Walchow and to the Nematopora and Fusispira beds of Minnesota (Upper Trenton). *Dianulites petropolitanus*, which in Russia ranges from the Walchow to the Wesenberg, is also identified in the same upper Trenton strata in Minnesota. *Batostoma fertile* and its variety *circulare* are said to be common to the Kunda formation of Russia and the Stictoporella bed (Black River) of Minnesota. *Hemiphragma irrasum*, found in the

Stictoporella, Rhinidictya, Phylloporina, and Clitambonites beds (Black River to Middle Trenton) of Minnesota, was identified from the Kunda of Russia. These forms are evidently of little value in direct detailed correlation, since the two species found in B_{II} would correlate that formation with the Upper Trenton, while the two found in B_{III} correlate that formation with the Black River and Lower Trenton. One of the species has a range equal to almost the whole Ordovician of Russia, and another has a very long range in America, so that no very valuable conclusions can be derived from them.

In considering the Bryozoa, it must be remembered that as yet only a few specimens belonging to the genus Nicholsonella, have been found in the American Beekmantown, and that the fairly large bryozoan fauna of the Chazy is as yet undescribed. The comparison of the range of genera in America and Russia does not, therefore, mean much, for many of the American genera now supposed to start in the Black River will probably be found to have their beginnings in the Chazy. There are, however, one or two interesting points to be noted in this connection. Bassler distributes the twenty-six species which he describes under eighteen genera (compare with seventy-seven species of trilobites in eighteen genera, and forty-five species of brachiopods in fifteen genera). Of these eighteen genera, only three are not found in America (compare with eight out of eighteen in the trilobites and eight of fifteen in the brachiopods). Three more are very peculiar, in that their American range begins much later than in Russia. One of them is known in this country from the Richmond to the Mississippian, another from the Niagara to the Coal Measures, and the third is wholly Devonian and Mississippian. A single one is found in the American Beekmantown, and the remaining eleven are known from the Stones River or Black River to the Richmond, excepting for one or two which do not start till the Middle or Upper Trenton. Looking over the table showing the range of the various species in Russia, we find that four species are confined to B_{II}, one is confined to B_{II} and B_{III}, nine are found only in B_{III}, eight pass from B into C, but do not extend further, and that three begin in B and continue into D, E, or F. Thus, among the Bryozoa, there are only five species common to B_{II} and B_{III}, and of these only one does not continue into C, while there are eleven common to B and C, which is very unlike the condition which obtains among the other classes. For instance, in the seventy-seven species of trilobites, nineteen are common to B_{II} and B_{III}, and only thirteen pass from B into C, and some of these cases must be considered as doubtful, since they come from that district on the

Walchow where the boundary between B_{III} and C_1 is indefinite. Still it is evident that thirteen out of seventy-seven is a much smaller proportion than eleven out of twenty-six. The only conclusion which it is possible to draw from the above rather remarkable array of evidence derived from the bryozoans is that both the species and genera have too great a vertical range to allow their use in direct correlations.

Cystidea.

Lamansky lists fifteen species of cystids, belonging to six genera (if Bolboporites can be called a genus), but he places no particular specific names after Cheirocrinus. As a matter of fact there are a considerable number of species of cystids not enumerated by Lamansky, but that does not affect the present purpose.

Of the six genera listed, three are unknown in America. Of the remaining three, Glyptocystites and Bolboporites appear in the Chazy, and Cheirocrinus in the Trenton. As with the Bryozoa, it must be remembered that the cystidean fauna of the Beekmantown is unknown. There is plenty of proof that cystideans were present, but most of our Beekmantown rocks are lithologically ill adapted either for the preservation or recovery of fossils.

Cephalopods.

Vaginoceras is of course the common genus in the Kunda, and that genus is represented in America by a single species found in the Chazy. Other genera, like Estonioceras and Planctoceras are unknown here.

Gastropods.

Gastropods make their first appearance in Russia in the Kunda, and the variety there is small. Of the four genera, two, Maclurites and Sinuites, are found in the Beekmantown, while Raphistoma appears first in the Chazy and Salpingostoma in the Stones River.

The fauna as a whole.

Bringing together what has been said above, it appears that out of the 186 species considered, five, all Bryozoa, have been considered as identical with species found in America, and these appear in the two countries in reverse order, and thus have no significance. Of the

genera, including organisms of all kinds except the Bryozoa, about half are not found in America. Of the genera common to the two countries, a few make their first appearance in America in the Beekmantown, a much larger proportion first appear in the Chazy or Stones River, and a few do not appear in America till Middle or late Trenton or even later. It is pointed out, however, that even in the case of certain of the genera reputed to be in both countries, the Russian representatives differ in marked ways from American species, and closer research is bound to show greater differences instead of greater likeness between the faunas of the two countries.

The fauna of the American Beekmantown is very imperfectly known, but the classes of fossils so far as relative abundance is concerned, are ranked in the order of: — first, cephalopods; second, gastropods; third, trilobites; fourth, ostracods; and finally brachiopods, cystids, and bryozoans, all in small numbers. On the other hand, the Walchow and Kunda formations have great numbers of trilobites and brachiopods, many cystids, cephalopods, and bryozoans, very few gastropods, a few ostracods, and crinoids. The two groups agree in the absence of pelecypods and corals.

If there were no other evidence than that afforded by the time of the first appearance of certain genera in Russia and America, it might well happen that the Walchow and Kunda formations might be correlated with the Chazy, but I do not see that they could be correlated with any younger strata. The comparison of the Russian with the Scandinavian sections, however, places such a correlation out of the question, and when one compares the faunas of these zones with the fauna of the Ceratopyge formation of Scandinavia, he realizes the antiquity of many of the groups, especially of the trilobites. Megalaspis, which is almost entirely confined to the Walchow and Kunda in Russia, is well represented in the Ceratopyge limestone of Scandinavia, one species being apparently common to the two formations and regions. Symphysurus, Nileus, Niobe, Eoharpes, and Ampyx are other genera connecting these formations with the Ceratopyge limestone, and even species of Nileus and Niobe are said to be common to the two.

On *a priori* grounds, we would not expect the Walchow and Kunda faunas to have much in common with the Beekmantown, if they are of the same age. The American fauna is an autochthonous one developed in the interior continental sea, out of the late Cambrian fauna. The fauna in Esthonia was, on the other hand, an invading fauna which was derived primarily from the Ceratopyge fauna of

Scandinavia, but that in turn though it received certain contributions from the late Cambrian faunas of the region in which it developed, owed much of its richness to types developed further south in the Tremadoc of Bohemia, France, and England. Having once gotten a foothold in northern Europe, the fauna developed very rapidly there, but apparently in an enclosed basin, for this fauna, as a whole, is unknown outside Scandinavia and Russia. Here, however, the factor of bottom control must be taken into account. As we have shown (p. 222), it is generally recognized that the black shales with the Didymograptus-Tetragraptus-Phyllograptus fauna were deposited at the same time as the "Orthoceras limestone," and in the same sea, but under different physical conditions. As is well known, the graptolite faunas did migrate, and very widely, but they did not carry the bottom fauna with them. If we adopt the rather generally accepted opinion that the graptolites were pelagic animals, supported either by floats or by their attachment to floating bodies such as sea weeds, we may conceive that the graptolites may have been distributed within a very short time, by the power of ocean currents, over very wide areas, while the influence of a strong current or of a cold current, impinging upon headlands, or the presence of vast expanses of sandy or muddy bottoms, may have long delayed the migration of bottom-living animals. We seem to have an excellent example of this in the case of Shumardia and certain associated species of the Ceratopyge limestone. In Sweden and Norway, Shumardia is rather abundant in the shale and limestone making up the Ceratopyge zone, and this zone is above the shale with *Dictyonema flabelliforme*, but below that of Tetragraptus and Phyllograptus. The Shumardia limestone of America, however, (at Point Lévis) is very high in the Tetragraptus-Phyllograptus series, so high even as the beginning of the range of Diplograptus. This case is the more striking since there are several species of the Scandinavian Shumardia-Ceratopyge fauna (*Shumardia pusilla* (Sars), *Agnostus sidenbladhi* Linnarsson, and *Symphysurus elongatus* Moberg and Segerberg) in this limestone high in the Lévis.

Under these conditions, if these species of the Ceratopyge fauna could not arrive in America until late Beekmantown, it is not surprising that many genera which originated in Europe during Beekmantown time, should not have arrived in America till the Chazy. I do not wish to be understood to advocate a general principle that homotaxial formations of separated continents are really one stage apart in age, but each particular case must be decided on its own merits.

Wierland group.

This series, held together by the presence throughout of *Echinosphaerites aurantium*, shows a decided change of faunas from bottom to top. The fauna of the oldest formation, the Dubowiki, is dominated by its asaphids, but these trilobites immediately lose their importance, and though they continue through the remainder of the Ordovician, they are present in limited variety and numbers. As previously stated, there are thirteen species which pass over from the Walchow and Kunda into the Dubowiki, but very few of them survive beyond this formation.

The Wierland fauna is, however, in general, an outgrowth of that which preceded it in the same area. Among the trilobites, notable new arrivals in this group are: — Chasmops, Sphaerocoryphe, Pseudosphaerexochus, Sphaerexochus, Acidaspis, Hoplolichas, Homolichas, Cyphaspis, Lonchodomas, and Ogygites (Basilicus of Schmidt). All of these genera, with the exception of Acidaspis and Cyphaspis could have arisen as modifications of types already in this region, so that we have, as true invaders only these two genera.

Among the brachiopods the important new genera are Christiania and Oxoplecia. The place of origin of these genera is unknown, but from their short ranges and limited variety in Russia, it seems probable that they are present there as migrants. Other brachipods introduced here are Plectambonites and Rafinesquina, but the dominant forms are the Clitambonites and Porambonites which continue from the formations below.

Among the gastropods, Bucania, Cymbularia, Eccyliopterus, Salpingostoma, and Subulites make their appearance first in this formation; while of the echinoderms, we find here the oldest species of Caryocystites, Echinosphaerites, Cryptocrinites, Cystoblastus, Cyathocystis, Hemicosmites, Hybocrinus, and Protocrinites. Among the sponges, Receptaculites is introduced at this time.

In running over this list of genera newly introduced into the Russian Ordovician during Wierland time, we are struck by the fact that we are here dealing with more familiar genera. Barring some of the cystids and one or two other genera, all these genera are known in America, and most of them from the Middle Ordovician. The greater part of these genera seem to have developed in the North European basin and to have migrated thence to America.

Certain of the genera are, in America, restricted to a belt along the

eastern Appalachians and to a small area in western Tennessee and Missouri (Kimmswick of Missouri), and do not occur in the usual Ordovician fauna of the great interior basin. The eastern Appalachian belt extends from Gaspé to Alabama, and includes the "Trenton" at Percé, the Quebec City at Quebec, the "Trenton" of southeastern Quebec, the Chazy and Rysedorph of New York, the Chambersburg of Pennsylvania, the Liberty Hall and Murat of central Virginia, the Holston, Ottosee, Lenoir, and Athens of southwestern Virginia and eastern Tennessee, and the "Trenton" of Alabama. This series includes formations of various ages from Chazy to Upper Trenton.

Russian genera which in America are restricted to the strata mentioned above are Sphaerexochus, Lonchodomas, Christiania, Oxoplecia, and Echinosphaerites. Genera prominent in this group, but only sparingly represented in the interior Ordovician are, Pseudosphaerexochus, Remopleurides, and Sphaerocoryphe.

Of the other genera introduced during Wierland time, Ogygites does not appear in America till late Trenton (Collingwood), Cymbularia is unknown, as are also Cryptocrinites, Cystoblastus, Cyathocystis, Hemicosmites, and Protocrinites. The other genera are more or less common throughout the Middle Ordovician faunas of America.

Some of the more striking of the Wierland guide fossils are absent from the Chazy, thus preventing what seems otherwise a very satisfactory direct correlation. These are Echinosphaerites, Christiania, and Oxoplecia. The fauna of the Chazy is, in fact, a curious mixture of native and immigrant types. All its large molluscan fauna is probably derived directly from the Beekmantown fauna, and most of its brachiopods are also American in origin. There is certainly nothing in northern Europe like its great profusion of rhynchonelloids, and its Orthidae and Strophomenidae may as well be native types as invaders. Even Camarella, the Chazy representative of the Porambonitidae, is probably of American stock, and does not really represent the Russian Porambonites. In Clitambonites, however, we have a true immigrant, which did very well for a time.

When we come to the trilobites, however, we begin to see the invaders. In the list we notice not only certain native genera, Bathyurellus, Isotelus, Isoteloides, Thaleops, and Glaphurus, but also many others, which are actually Russian or derived from Russian stocks. These are, *Russian:* — Eoharpes, Lonchodomas, Remopleurides, Nileus, Ceraurus, Pseudosphaerexochus, Nieszkowskia, Sphaerocoryphe, Sphaerexochus, and Pterygometopus; derived from *Russian stock:* — Cybeloides, Pliomerops, Vogdesia, and Heliomera.

These genera may be divided into two groups, first those appearing first in the Walchow and Kunda in Russia, and second, those making their first appearance in the Wierland in Russia. In the first group we find Eoharpes (also in Beekmantown), Remopleurides, Nileus, Ceraurus, Nieszkowskia, and Pterygometopus. In the second group are only Lonchodomas, Pseudosphaerexochus, Sphaerexochus, and Sphaerocoryphe. Cybeloides, Pliomerops, Vogdesia, and Heliomera are all derived from forms appearing first in the lower group in Russia.

From this analysis of the Chazy fauna it appears that, while the fauna is in very large proportion of American origin, it has present in it a considerable Russian element which is largely derived from genera present in the Walchow and Kunda formations. Why certain genera such as Echinosphaerites, Oxoplecia, Plectambonites, and Christiania from Russia, and Tretaspis, Nidulites, and Agnostus from Scandinavia, which reached North America somewhere about this time, did not get into the typical Chazy is a perplexing question. So far as bottom control is concerned, there seems to have been no barrier, and only two possible explanations occur, namely, either their natural habitat was fully occupied, or they did not reach America till later than the time of the typical Chazy; the latter explanation seems, in view of all the facts, the more probable.

DETAILED SECTIONS IN RUSSIA.

Sections arranged in order from east to west.

SECTION ON THE WALCHOW. (Given by Lamansky (29)).

$B_{III\gamma}$. Thick-bedded compact limestone at Sapolek and Bylstchina, and at the base of the quarries at St. Michael Archangel. 6 meters = 18.35 m.

$B_{III\beta}$. Rusty and spotted limestone at the base, followed by one or more layers of "Linsenschicht," these being succeeded by red and yellow spotted layers. The Linsenschicht is one meter above the base. 3.5 m. = 12.35 m.

$B_{III\alpha}$. Bluish green limestone with fine-grained glauconite at the base, but none above. 3 m. = 8.85 m.

$B_{II\gamma}$. Compact limestone with some glauconite. Loses compactness quickly on weathering. 2.4 to 2.7 m. = 5.85 m.

$B_{II\beta}$. Thin-bedded limestone with red and yellow spots. Very little glauconite. 1.8 m. = 3.45 m.

$B_{II\alpha}$. Thick-bedded, red, yellow, violet, and gray-green limestone. 1.65 to 1.80 m. = 1.65 m.

SECTION ON THE WALCHOW. (Measured by the writer).

The highest beds are exposed in the quarries at Dubowiki. Zones 11 to 9 were measured near the steamboat landing at St. Michael Archangel, and the remainder of the section on the eastern bank of the Walchow opposite Iswos.

11. Light gray to yellowish magnesian limestone in beds one inch to one foot in thickness. Some layers are fine grained and dense, while others are porous, the fossils occurring as hollow moulds. *Christiania oblonga* common and characteristic. Reval formation. 25 ft. = 112 ft.±
10. Soft gray limestone which breaks down readily to a sticky calcareous mud. Entire trilobites and other perfect fossils common. *Echinosphaerites aurantium* abundant.
Dubowiki formation. Base not exposed. 14 ft. = 87 ft.±
9. Concealed to river level. 23 ft. = 73 ft.±
(According to the thickness given by Lamansky the greater part of the concealed interval here would be filled by the "Orthoceras" limestone (Kunda formation)).
8. Red and green limestone enclosing the "Lower Linsenschicht." 3 ft. = 50 ft.
7. Thin-bedded limestone and shale, with 3 feet of rather solid limestone at the top. $B_{II\delta}$ ($B_{III\alpha}$ of Lamansky). 9 ft. = 47 ft.
6. Thick-bedded gray limestone with shaly partings. ($B_{II\gamma}$) 10 ft. 6 in. = 38 ft.
5. Thin-bedded, shaly limestone. ($B_{II\beta}$). 5 ft. 6 in. = 27 ft. 6 in.
4. Heavy-bedded red limestone with abundant glauconite and echinoderm fragments. ($B_{II\alpha}$). 6 ft. = 22 ft.
3. Sandy shale. 1 ft. = 16 ft.
Zones 3–7, and the lower part of zone 8, below the Linsenschicht, belong to the Walchow formation.
2. Concealed. 3 ft. = 15 ft.
1. White and gray sandstone to the river's edge. Zones 1 and 2 belong to the Packerort formation. 12 ft. = 12 ft.

River Lawa at Wassilkowa. (Measured by the writer).

9. Thin, irregularly bedded, gray limestone and shale. 20 ft. = 72 ft.
8. Bright red and green variegated limestone in thin beds. $B_{II\delta}$. ($B_{III\alpha}$ (partim) of Lamansky). 4 ft. = 52 ft.
7. Thick-bedded light, blue-gray limestone. ($B_{II\gamma}$). 11 ft. = 48 ft.
6. Thin-bedded, irregular, blue limestone with thick shaly partings. ($B_{II\beta}$). 13 ft. = 37 ft.
5. Heavy-bedded red and green limestone with few fossils. ($B_{II\alpha}$). 6 ft. = 24 ft.
4. Green sand and clay. (Glauconite sand). 6 ft. = 18 ft.

   Zones 4 to 8 and the lower part of 9 make up the Walchow formation. The "Linsenschicht" is present in 9, but unfortunately I did not note its exact position.
3. Black shale. (Dictyonema shale). 1 ft. = 12 ft.
2. White, gray, and yellow sand, very irregularly bedded. It crumbles readily at the touch and contains numerous specimens of *Obolus apollinis* along the planes of cross-bedding. Zones 2 and 3 represent the Packerort formation. 10 ft. = 11 ft.
1. Very hard red sandstone, base not seen. 1 ft. = 1 ft.

Papowka, south of Petrograd. (Measured by the writer).

9. Thick-bedded, gray, fine-grained limestone with numerous Orthoceratites. It contains two red layers, each one foot in thickness. 18 ft. = 57 ft.
8. Red limestone full of Orthoceratites. 1 ft. = 39 ft.
7. Heavy-bedded dolomitic limestone which contains cavities from which fossils have been dissolved. Orthoceratites in top foot. 7 ft. = 38 ft.
6. Shaly limestone with "linsen." 5 in. = 31 ft.

   Zones 6–9 represent the Kunda formation.
5. Thin-bedded limestone with much clay and shale. 12 ft. = 30 ft. 6 in.
4. Thick-bedded green and red limestone. 7 ft. = 18 ft. 6 in.
3. Green sandy shale. 1 ft. = 11 ft. 6 in.

   Zones 3–5 represent the Walchow formation.
2. Black shale with only microscopic fossils. 4 ft. 6 in. = 10 ft. 6 in.

1. Green, white, and red sandstone with numerous fragments of Obolus. Base not seen. 6 ft. = 6 ft.
   Zones 1 and 2 represent the Packerort formation.

SECTION AT NARWA. (Given by Schmidt (47) in the Guide for the excursions of the St. Petersburg meeting of the International Geological Congress).

$C_{1\beta}$. Echinosphaeritenkalk. Dolomite. 3.0 m. = 16.9 m.
$C_{1\alpha}$. Upper Linsenschicht. .3 m. = 13.9 m.
$B_{III\beta}$. Vaginoceras limestone. Dolomite. 3.0 m. = 13.6 m.
$B_{III\alpha}$. Lower Linsenschicht. .3 m. = 10.6 m.
B_{II}. Glauconite limestone. 3.3 m. = 10.3 m.
B_{I}. Glauconite sandstone with concretions of bituminous limestone with Dictyonema. .2 m. = 7. m.
A_{III}. Red Obolus sandstone showing cross-bedding. 2.6 m. = 6.8 m.
A_{II}. White fucoidal sandstone with sand concretions. 4.2 m. = 4.2 m.

NARWA. (Measured by the writer). Plate 6.

8. Gray limestone, dolomitic, heavy-bedded, and with few fossils at the top, thin-bedded and with numerous Orthoceratites in the lower portion. 10 ft. = 36 ft. 10 in.
7. Linsenschicht. 15 in. = 26 ft. 10 in.
   Zones 7 and 8 represent the Kunda formation.
6. Hard thick-bedded gray limestone. 3 ft. = 25 ft. 7 in.
5. Impure red limestone with numerous *M. planilimbata.* Top layer a much weathered rusty one, full of holes. 8 ft. = 22 ft. 7 in.
4. Red clay-shale. 3 in. = 14 ft. 7 in.
3. Green clayey sand. 4 in. = 14 ft. 4 in.
   Zones 3–6 represent the Walchow formation.
2. Yellow, white and reddish massive and cross-bedded sandstone with very numerous Obolus. At the base is a layer of rounded, hard, sandstone pebbles, three, four, and ten inches in diameter. Much pyrites in lower two or three feet, sometimes in hard layers. 11 ft. = 14 ft.
   Zone 2 represents the Packerort formation.
1. Almost white, thin-bedded sandstone. Base not seen. 3 ft. = 3 ft.

   Zone 1 represents the Esthonia formation.

Asserien. (Zones 16 to 13 are well shown in the quarries and along the railroad about two miles south of the cement plant at Asserien. Zones 13 to 1 are well exposed at and below the large quarry at the edge of the cliff about a mile west of the plant. Measured by Dr. Twenhofel and the writer).

16. Fine-grained magnesian limestone in layers one to three inches thick. Very few fossils. 6 ft. = 76 ft. 1 in.
15. Thick-bedded, fine-grained compact magnesian limestone with an abundance of Orthoceratites in the lower three feet. Some layers are porous and show open moulds of fossils. 8 ft. = 70 ft. 1 in.
    Zones 15 and 16 belong to the Reval formation.
14. Thick- and thin-bedded gray limestone without much shale. Echinosphaerites especially abundant in the lower part. 7 ft. 6 in. = 62 ft. 1 in.
13. Light gray, rather thick-bedded limestone without shale, but becoming soft and shaly on weathering. This zone contains more or less "linsen" throughout, but they are especially abundant in the lower three feet. 8 ft. = 54 ft. 7 in.
    Zones 13 and 14 make up the Dubowiki formation.
12. Thick- and thin-bedded gray limestone which becomes soft and shaly on weathering. Many Vaginoceras present. 14 ft. 8 in. = 46 ft. 7 in.
11. Lower "Linsenschicht." 9 in. = 31 ft. 11 in.
    Zones 11 and 12 represent the Kunda formation.
10. Thick-bedded gray limestone. 3 ft. 6 in. = 31 ft. 2 in.
9. Thin-bedded limestone and shale. 6 in. = 27 ft. 8 in.
8. Thick-bedded, hard, reddish limestone with glauconite. 3 ft. 6 in. = 27 ft. 2 in.
7. Clay and limestone. 8 in. = 23 ft. 8 in.
6. Green clay and sandstone. 6 ft. 3 in. = 23 ft. 0 in.
    Zones 6 to 10 form the Walchow formation.
5. Thin-bedded, soft, yellowish clay-shale. 4 ft. = 16 ft. 9 in.
4. Red and yellow limonite. 3 in. = 12 ft. 9 in.
3. Thin-bedded black shale with thin layers of sandstone in the lower half. 7 ft. = 12 ft. 6 in.
2. Light yellow and red cross-bedded sandstone, with lenses of thin, black shale in layers one fourth to one inch in thickness and with black deposits on the bedding planes. 3 ft. 3 in. = 5 ft. 6 in.

1. Yellow and white sandstone with numerous Obolus, one layer. 2 ft. 3 in. = 2 ft. 3 in.
Zones 1–5 represent the Packerort formation.
Concealed to water-level.

ONTIKA. (Top 206 ft. above sea-level. Measured by Dr. Twenhofel and the writer).

11. Thin-bedded soft limestone with *Echinosphaerites aurantium.* 5 ft. = 78 ft. 5 in.
10. Thin-bedded light gray limestone with numerous Orthoceratites and many small "linsen." Upper Linsenschicht. 7 ft. 6 in. = 73 ft. 5 in.
Zones 10 and 11 represent the Dubowiki formation.
9. Thin-bedded light gray shaly limestone with numerous Orthoceratites. A nine inch shaly parting is present four ft. above the base. 18 ft. 6 in. = 65 ft. 11 in.
8. Lower Linsenschicht. 8 in. = 47 ft. 5 in.
Zones 8 and 9 represent the Kunda formation.
7. Heavy-bedded gray limestone with nine inches of shale at top. 5 ft. = 46 ft. 9 in.
6. Thin-bedded nodular and shaly limestone 6 in. = 41 ft. 9 in.
5. Heavy-bedded reddish limestone with green patches, weathering yellowish. 4 ft. 9 in. = 41 ft. 3 in.
4. Green sandy shale. 4 ft. = 36 ft. 6 in.
Zones 4 to 7 represent the Walchow formation.
3. Hard red limonite layer. 3 in. = 32 ft. 6 in.
2. Black shale, no fossils seen. 7 ft. 3 in. = 32 ft. 3 in.
1. Cross-bedded reddish and white sandstone which disintegrates to loose sand. Base not seen. 25 ft. = 25 ft.
Zones 1 to 3 represent the Packerort formation.
Concealed to water, 127 ft.

CATHERINE PARK, REVAL. (Measured by the writer).

7 Thin-bedded often shaly limestone. The highest layers in the quarries. Echinosphaerites and other cystids common. Kuckers formation. 4 ft. = 47 ft.
6. Light gray compact fine-grained limestone in beds 8 to 15 inches in thickness. Fossils are very rare. Certain layers contain vertical, tube-like fillings suggesting borings. Largely quarried. 28 ft. = 43 ft.

5. Upper Linsenschicht. 1 ft. = 15 ft.
Zones 5 and 6 represent the Reval formation.
4. Two and one half feet of gray limestone with one foot of yellowish dolomite below it. 3 ft. 6 in. = 14 ft.
3. Conglomerate with pebbles of green glauconitic limestone. 6 in. = 10 ft. 6 in.
Zones 3 and 4 represent the Kunda formation.
2. Green glauconitic limestone with most glauconite in the top layer. 7 ft. = 10 ft.
1. Red calcareous sandstone with glauconite grains. Base not seen. 3 ft. = 3 ft.
Zones 1 and 2 represent the Walchow formation.

Church Jegelecht. (Village Joa on the Jaggoul road, west of Reval. Section by Schmidt (47)).

Upper Linsenschicht.	.3 m. = 8.0 m.
Vaginoceras limestone.	3.2 m. = 7.7 m.
Lower Linsenschicht.	.2 m. = 4.5 m.
Glauconite limestone.	3.1 m. = 4.3 m.
Glauconite sandstone.	.8 m. = 1.2 m.
Dictyonema shale. Base not seen.	.4 m. = .4 m.

Below Packerort light-house. (Two miles north of Baltishport. Measured by the writer). Plate 7.

10. Heavy-bedded dolomitic limestone with few fossils. Weathers dull yellow. Best exposed in the neighborhood of Baltishport. Top not seen. 25 ft. = 80 ft. 1 in.
9. Linsenschicht. 10 in. = 55 ft. 1 in.
Zones 9 and 10 represent the Reval formation.
8. Thick-bedded limestone, the bottom layer full of pebbles of limestone and irregular fragments of phosphatic shale. Kunda formation. 3 ft. 6 in. = 54 ft. 3 in.
7. Thin-bedded limestone and shale. 1 ft. 3 in. = 50 ft. 9 in.
6. Green limestone, very full of glauconite, especially at the base. 2 ft. 6 in. = 49 ft. 6 in.
5. Soft, green sandstone. 11 ft. = 47 ft.
Zones 5 to 7 represent the Walchow formation.
4. Dark clay-shale, weathering to a light gray. Some layers contain numerous graptolites. The shale rests

in hollows in the sandstone below and the strata bend up and down with the irregularities of the subjacent surface. At the base is a bed of limonite two to three inches in thickness. 18 to 13 ft. = 36 ft.

3. Thick, irregularly cross-bedded sandstone with some specimens of Obolus in the upper layer. Thickness variable. 5 to 10 ft. = 23 ft.

2. Thin strata of black shale alternating with layers of yellow or red sandstone. The shale is in beds one to ten inches thick and is similar in character to that above. The basal portion consists of conglomerate with boulders of sandstone from one to five feet in diameter, and also small pebbles cemented together by limonite and pyrite. 5 ft. = 13 ft.

Zones 2 to 4 represent the Packerort formation.

1. Hard, white, coarse-grained sandstone. Base not seen. Top of Esthonia formation. 8 ft. = 8 ft.

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PLATE 1.

PLATE 1.

Sketch map of the Lower Palaeozoic in the Baltic Provinces of Russia.

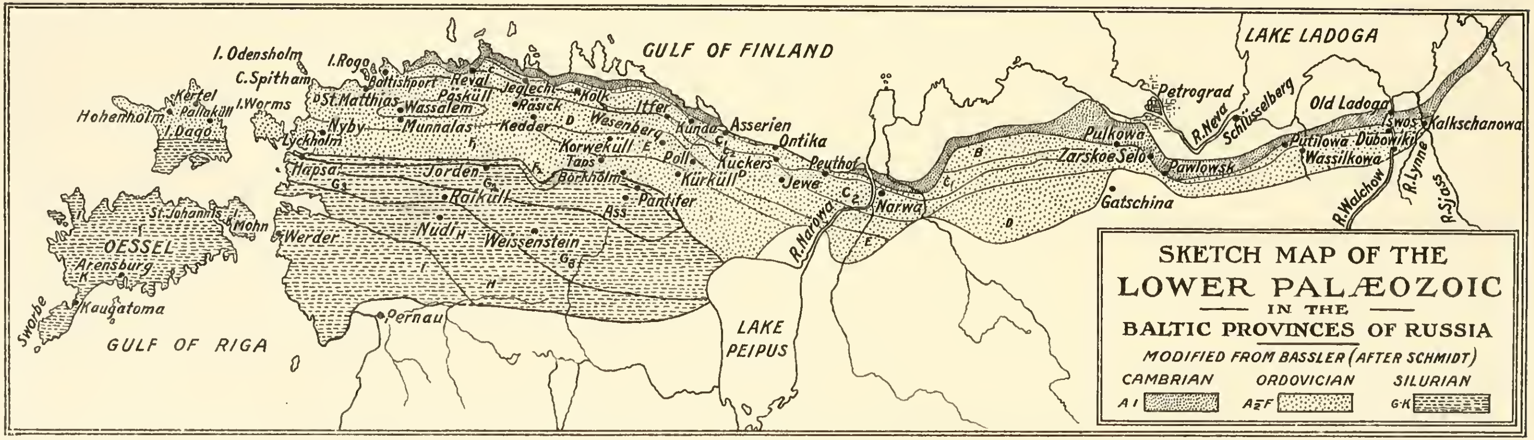
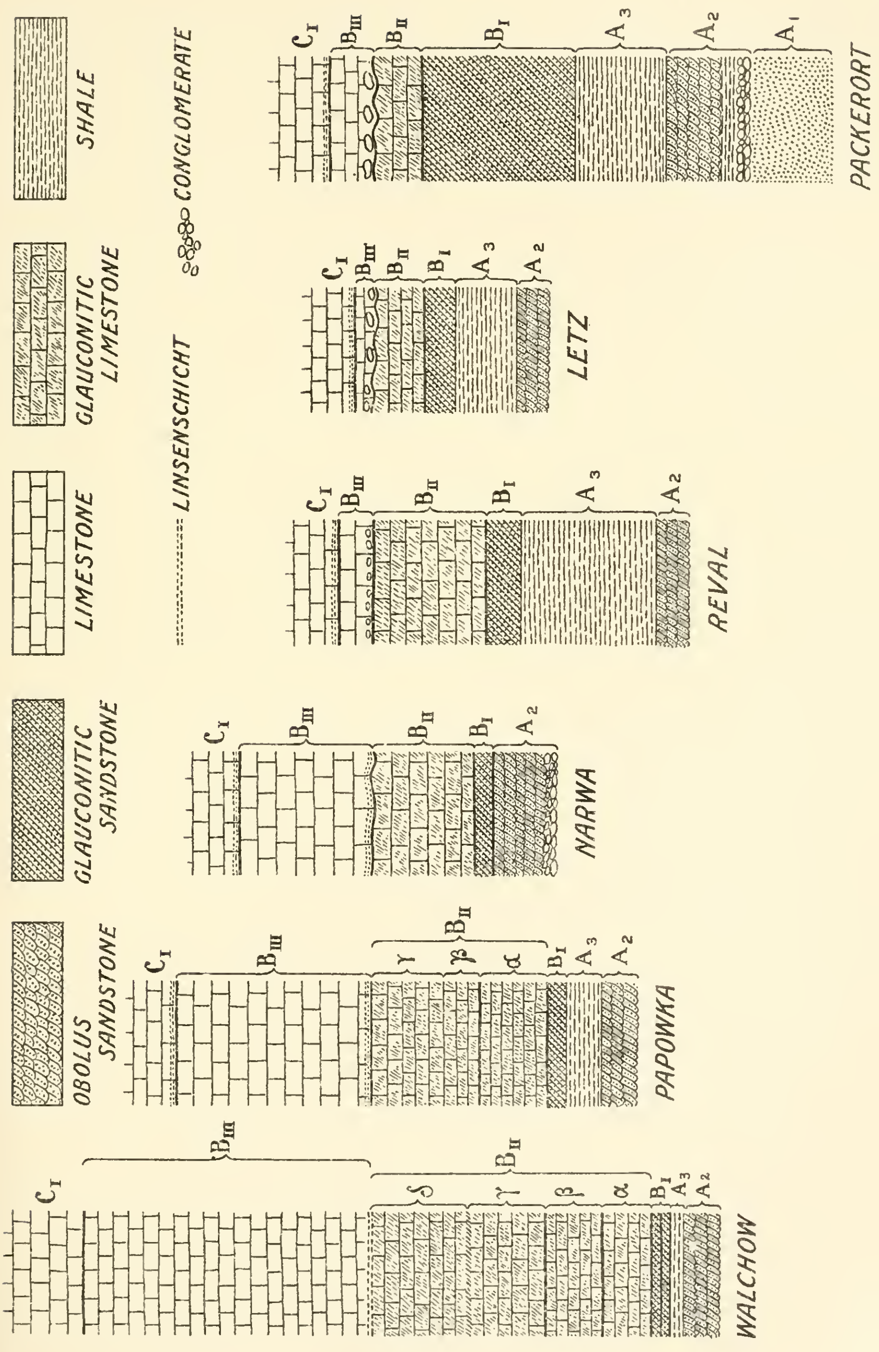

SKETCH MAP OF THE
LOWER PALÆOZOIC
IN THE
BALTIC PROVINCES OF RUSSIA
MODIFIED FROM BASSLER (AFTER SCHMIDT)
CAMBRIAN
ORDOVICIAN
SILURIAN
A I
A2-F
G-K
GULF OF FINLAND
GULF OF RIGA
LAKE LADOGA
LAKE PEIPUS
OESSEL
I. Dagö
I. Odensholm
C. Spitham
I. Rogo
I. Worms
I. Mohn
Hohenholm
Kertel
Pallaküll
Baltishport
Reval
Päsküll
Jeglecht
Kolk
Rasick
St. Matthias
Wassalem
Nyby
Munnalas
Kedder
Wesenberg
Itfer
Kunda
Asserien
Ontika
Korwekull
Taps
Poll
Kuckers
Peuthof
Kürküll
Jewe
Börkholm
Pantifer
Ass
Lyckholm
Hapsa
Jorden
Raiküll
Nudi
Weissenstein
Werder
St. Johannis
Arensburg
Kaugatoma
Sworbe
Pernau
Narwa
R. Narowa
Pulkowa
Zarskoe Selo
Pawlowsk
Gatschina
Petrograd
R. Neva
Schlüsselberg
Old Ladoga
Putilowa
Dubowiki
Wassilkowa
Iswos
Kalkschanowa
R. Walchow
R. Lynne
R. Sjass

PLATE 2.

PLATE 2.

Comparative table of sections of the Lower Ordovician strata in the Governments of Petrograd and Esthonia, Russia. This diagram is redrawn with some alterations from one published by Lamansky. A_1 is the Lower Cambrian Esthonia formation, A_2 the Obolus sandstone, A_3 the Dictyonema shale, B_I the Glauconite sandstone, B_{II} the Glauconite limestone with its subzones, and B_{III} the Orthoceras limestone (Kunda formation). The $B_{II\delta}$ is the $B_{III\alpha}$ of Lamansky. A_2 and A_3 make up the Packerort formation and B_I and B_{II} are the Walchow formation.

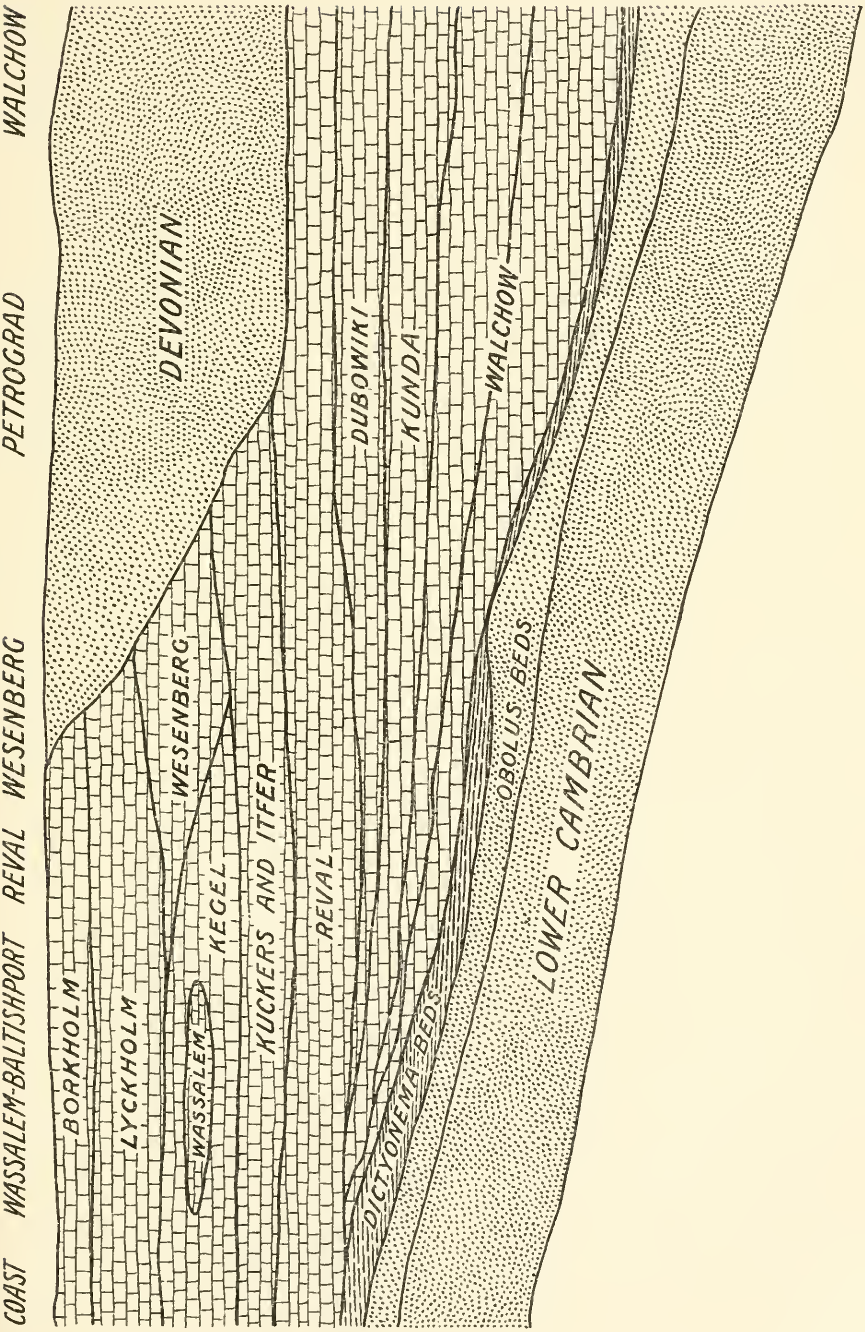


HELIOTYPE CO., BOSTON

PLATE 3.

PLATE 3.

Sketch showing the probable relationship of the various Ordovician formations in a west-east section from the shore of the Baltic to the Walchow River. Not drawn to scale. With the Kuckers and Itfer is included the Jewe.



HELIOTYPE CO., BOSTON

PLATE 4.

PLATE 4.

Fig. 1. An exposure of the lower beds of the Ordovician (Walchow and Packerort formations) on the Lawa at Wassilkowa. The top of the Lower Cambrian is at water-level; the Obolus sandstone, the Dictyonema shale, and the Glauconitic sandstone all occur in the fifteen feet of strata beneath the projecting beds seen in the middle of the figure. The conspicuous beds are the lowest limestone and belong to the zone of *Megalaspis planilimbata* ($B_{II\alpha}$). Above this are seen the softer strata of $B_{II\beta}$, then the harder limestone of $B_{II\gamma}$, and at the top, the zone of *Asaphus expansus*, or $B_{II\delta}$ ($B_{III\alpha}$ of Lamansky).

Fig. 2. Quarry in the upper part of the Walchow and the lower part of the Kunda at Putilowa. Both these localities are south of Lake Ladoga and east of Petrograd, Russia.

1

2

PLATE 5.

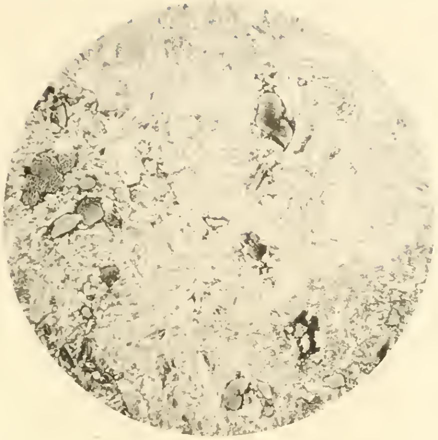
PLATE 5.

Fig. 1. Thin section of glauconitic limestone from Putilowa, Russia. The darker grains are glauconite; note the extent to which they are altered to opaque limonite, especially in the large grain near the edge to the left.

Fig. 2. Another section from Putilowa in which glauconite is somewhat more abundant and less altered.

Fig. 3. A thin section of limestone from the zone of *Asaphus expansus* (top of the Walchow) in a quarry opposite Iswos, Russia.

Note that all three of these slides show the limestone to be made up almost entirely of fragments of fossils, largely trilobites, brachiopods, and cystids. All magnified about 10 diameters.



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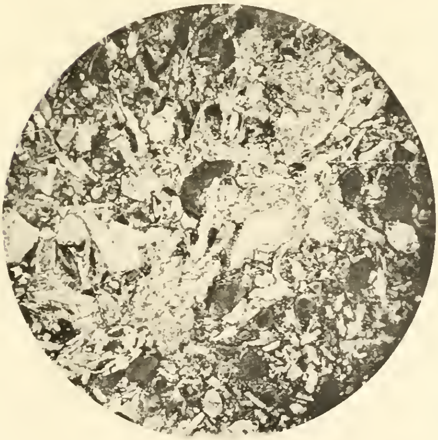

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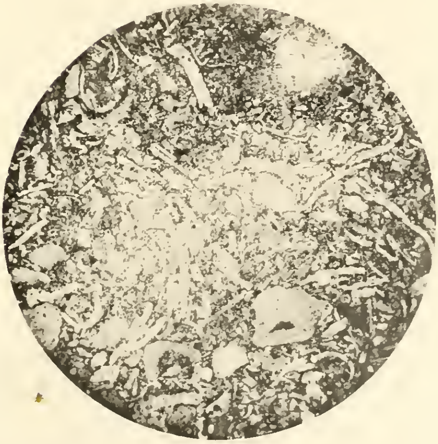

3

PLATE 6.

PLATE 6.

Fig. 1. Cross-bedded limestone at the top of the Wassalem at the type-locality.

Fig. 2. Cliff on the western bank of the Narowa at Narwa, Russia. The Obolus sandstone is seen at the base, and is 11 feet thick. The reëntrant at the top of the sandstone indicates the position of the Glauconite sandstone, which is only 4 inches thick. The lower half of the remaining height of the cliff is occupied by the Walchow formation, and the upper half by the Kunda.

1

2

PLATE 7.

PLATE 7.

Fig. 1. Basal conglomerate of the Obolus sandstone at Packerort, Russia.

Fig. 2. The "Glint" beneath Packerort light-house. Height, 80 feet. At the bottom are seen the upper 8 feet of the Lower Cambrian, and the contact with the Ordovician is indicated by the lower undercutting, which is at the base of the Obolus sandstone. Above this sandstone may be seen the Dictyonema shales and then the Glauconite sandstone, making the second undercutting. Above this are the thin representatives of the Walchow and Kunda formations, and at the top, the overhanging Reval dolomite, the Dubowiki being absent.

1

2

PLATE 8.

PLATE 8.

Table showing the writer's interpretation of the sections and correlation of the subdivisions of the Ordovician of Esthonia and Scandinavia with those of certain localities in North America.

The first section is from the coast at Kunda south through Wesenberg, the second from the coast at Packerort near Baltishport south through Wassalem to the vicinity of Hapsal: all of these places being in Esthonia, Russia. The next five are all in Sweden, and the eighth is a generalized section at Christiania, Norway. Of the remainder, all, except the one at Ottawa, Canada, are in the United States. The one in the Champlain Valley includes strata in both New York and Vermont, Chambersburg and Bellefonte are both in Pennsylvania, the section from Kentucky is that near Lexington, and the one in central New York is a combination of sections near Trenton Falls and Utica.

ORDOVICIAN — Upper Ordovician / Middle Ordovician / Lower Ordovician

Kunda Wesenberg	Borkholm; Lyckholm; Wesenberg; Jewe; Itfer; Kuckers; Reval; Dubowiki; Kunda; Walchow; Packerort; Esthonia
Baltishport Hapsal	Borkholm; Lyckholm; Wassalem; Kegel; Jewe; Itfer; Kuckers; Reval; Kunda; Walchow; Packerort; Esthonia
Dalecarlia	Leptaena limestone; Trinucleus shale; Macrourus limestone; Chasmops limestone; Ancistroceras limestone; Chiron limestone; Platyurus limestone; Gigas limestone; Expansus ls.; Limbata ls.; Planilimbata-Tetragraptus zone; Ceratopyge ls; Glauconite ss.; Obolus conglomerate; Pre-Cambrian
Kinnekulle	Brachiopod shale; Trinucleus shale; Chasmops limestone; Ancistroceras limestone; Chiron limestone; Platyurus limestone; Gigas limestone; Limbata ls.; Tetragraptus shale; Ceratopyge limestone; Upper Cambrian
Oeland	Chasmops limestone; Ancistroceras limestone; Chiron limestone; Platyurus limestone; Gigas limestone; Limbata ls.; Planilimbata limestone; Ceratopyge ls; Ceratopyge sh.; Dictyonema sh.; Obolus ss.; Middle Upper Cambrian
Jemtland	Brachiopod shale; ?; Macrourus limestone; Chasmops-Clingani zone; Nemograptus-Ogygiocaris shale; G. hinksi shale; Platyurus limestone; Gigas limestone; Expansus ls.; Limbata ls.; Planilimbata Tetragraptus zone; Upper Cambrian
Scania	Trinucleus shale; P. linearis shale; Clingani shale; Nemograptus shale; G. hinksi shale; Geminus shale; Phyllograptus shale; Orthoceras ls.; Tetragraptus shale; Ceratopyge shale; Dictyonema sh.; Upper Cambrian
Christiania	5; 4c; 4bδ; 4bγ; 4bβ; 4bα; 4aβ; 4aα; Gigas limestone; Expansus ls.; Limbata ls.; Tetragraptus shale; Ceratopyge ls.; Ceratopyge sh.; Dictyonema sh.; Upper Cambrian
Champlain Valley	Cumberland Head shale; Glens Falls; Lorette; Leray; Lowville; Valcour; Crown Point; Day Point; Beekmantown: Cassin, C, B, A; Cambrian
Chambersburg	Martinsburg; Echinosphaerites; Chambersburg; Echinosphaerites; Stones River; Maclurites zone; Beekmantown; Stonehenge; Knox
Bellefonte	Martinsburg; "Trenton"; Hermitage; Echinosphaerites; Leray; Tetradium; Stones River; Bellefonte; Axeman; Nittany; Stonehenge; Knox
So. West Virginia	Bays; Sevier; Moccasin; Ottosee Echinosphaerites; Athens; Stones River; Knox
Kentucky	Maysville; Eden; Cynthiana; Perrysville; Flanagan; Bigby; Willmore; Hermitage; Curdsville; Tyrone; Oregon; Camp Nelson
Minnesota	Stewartville; Prosser; Decorah; Platteville
Ottawa Ontario	Richmond; Lorraine; "Utica"; Collingwood; Upper Picton; Lower Picton; Prasopora zone; Hull; Rockland; Leray; Lowville; Pamelia; Aylmer; Beauharnois; Potsdam
Central New York	Lorraine; Frankfort; Utica; Lower Picton; Prasopora zone; Glens Falls; Lorette; Leray; Lowville; Little Falls; Pre-Cambrian

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Reports on the Results of Dredging Operations in 1877, 1878, 1879, and 1880, in charge of ALEXANDER AGASSIZ, by the U. S. Coast Survey Steamer "Blake," as follows:—

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A. E. VERRILL. The Alcyonaria of the "Blake."

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K. BRANDT. The Thalassicolae.
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H. J. HANSEN. The Schizopods.
HAROLD HEATH. Solenogaster.
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H. L. CLARK. The Holothurians.
H. L. CLARK. The Ophiurans.
—— The Volcanic Rocks.
—— The Coralliferous Limestones.
S. HENSHAW. The Insects.
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AT HARVARD COLLEGE.
Vol. LVI. No. 4.

GEOLOGICAL SERIES, Vol. X. SHALER MEMORIAL SERIES, No. 3.

EXPEDITION TO THE BALTIC PROVINCES OF RUSSIA AND SCANDINAVIA, 1914.

PART 2.—THE SILURIAN AND HIGH ORDOVICIAN STRATA OF ESTHONIA, RUSSIA AND THEIR FAUNAS.

PART 3.—AN INTERPRETATION OF THE SILURIAN SECTION OF GOTLAND.

By W. H. Twenhofel.

With Five Plates.

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[1] Bull. M. C. Z., Vol. XLVI., No. 4, April, 1905, 22 pp.
[2] Bull. M. C. Z., Vol. XLVI., No. 6, July, 1905, 4 pp., 1 pl.
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[9] Bull. M. C. Z., Vol. L., No. 6, February, 1907, 48 pp., 18 pls.
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BY W. H. TWENHOFEL.

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PART 2.

PART 3.

INTRODUCTION.

THE present paper is based on work done under the auspices of the Shaler Memorial fund. In company with Prof. Percy E. Raymond, an expedition was undertaken in the summer of 1914 for the purpose of examining the Cambrian, Ordovician, and Silurian strata exposed around the Baltic in Russia, Sweden, and Norway, with the object in view of attempting a correlation with strata of the same systems of eastern North America. The writer was primarily concerned with the highest Ordovician and Silurian, while the Cambrian and the remainder of the Ordovician were studied by Professor Raymond, although mutual assistance was rendered. The outbreak of the war to some extent necessitated a curtailment of the study, but in my case this amounted to the loss of only a few days' work in northern Gotland and a considerable shortening of the time allotted to Norway. The failure to see certain sections of northern Gotland will be ultimately overcome by detailed collections which have been made (1915)

from these sections under the direction of Dr. Henry Munthe of the Swedish Geological Survey. Nearly all of southern Gotland and parts of northern Gotland were examined, much of the study being under the guidance of Dr. Munthe. About ten days were spent in Dalarne studying the Leptaena kalk, while Professor Raymond made collections from the Brachiopod shales and Silurian horizons of southern Sweden.

In the Kristiana region of Norway, the Malmo and Ringerike Silurian sections were studied, the latter under the guidance of Drs. Johan Kiaer and Olaf Holtedahl of the University of Kristiana, and, as the facies of the latter section is quite similar to that of the Silurian of eastern America, while the other Norwegian Silurian sections are of a quite different lithology, the failure to see the latter is not of great importance, especially since they have been exhaustively studied by Professor Kiaer.

The Russian Silurian and higher Ordovician were carefully examined, each of the type-sections of Schmidt being studied, in addition to many other outcrops.

It was also desired to see some of the English sections; but this proved to be impossible. This misfortune was largely made good, however, through the courtesy of Dr. Audrey Strahan, Director of the Geological Survey of England and Wales, and different members of his staff, particularly Mr. John Pringle, who placed, at my disposal for study, complete detailed collections from Silurian and high Ordovician strata, together with the general collections of the Museum of Practical Geology. The kindness of Dr. F. Cowper Reed of Cambridge University gave the opportunity to examine such collections at the Sedgwick Museum of Cambridge as had been made from the Keisley and Chair of Kildare limestones, while Dr. F. A. Bather of the British Museum very courteously permitted an examination of desired parts of that Museum's magnificent collections.

In this paper merely a preliminary discussion of the Russian sections is given, as the fossils have not yet been studied.

The opportunity is taken at this time to acknowledge the many courtesies and the unselfish kindness received from all from whom assistance was desired. Thanks are particularly due to Baron Freytag-Loringhoven of the island of Oesel, Baron Toll of Kuckers, Baron Maidel of Eichenheim, Baron Rosen of Lyckholm, Herr E. von Wahl of Addifer, the Directors of the cement plants at Port Kunda and Asserien, Dr. I. P. Tolmacev of the Imperial Academy of Petrograd, Drs. Henry Munthe, Johan Kiaer, Olaf Holtedahl, Audrey Strahan,

F. A. Bather, F. R. C. Reed, Mr. John Pringle, as well as many others who rendered assistance. Thanks are also due Professor Raymond for the cordial comradeship and great assistance afforded during the study of the Baltic sequence. Dr. R. S. Bassler has kindly read the paper for which I am grateful.

THE RUSSIAN SECTION.

Work on the Russian section of Esthonia was begun on June 15, and closed on July 17. Fossils were collected wherever it was possible. These have not yet reached the United States and pending their arrival no detailed discussion of the correlation will be given.

Previous work. Many foreign geologists have studied the Esthonian sections of the Russian Ordovician and Silurian and their faunas. To attempt a review of the work of these students in detail is out of question, and one must be content with merely a brief reference to a few of those whose contributions are of greatest importance. Those whose studies are perhaps of most value are:—

Pander. Beiträge zur geognosie der russichen reiches. Nieszkowski. Versuch einer monographie der in den silurischen schichten der Ostseeprovincen vorkommenden trilobiten. Archiv. fur naturk. Liv-, Est-, und Kurlands, 1857, ser. 1, **2**. Dybowski. Monographie der Zoantharia Sclerodermata rugosa aus der silurformation Estlands, Nord-Livlands, und der Insel Gotland. Archiv. fur naturk., Liv-, Est-, und Kurlands, 1873, ser. 1, **5**. Koken. Bull. Acad. imp. sci. St. Petersburg, 1897, ser. 5, **7**, no. 2. Eichwald. Bull. Soc. nat. Moscow, 1854, 1855. The most extensive contributor to the knowledge of the Baltic section in Russia was F. Schmidt, who in numerous papers, beginning in 1858, has described the section and its faunas.[1] For more than fifty years he wandered over the Russian Baltic sections, collecting fossils, studying the stratigraphy, and making observations in many fields.

A more recent paper by Bassler[2] discusses the Ordovician section, comprehensively describes the Bryozoa, and attempts a correlation with American equivalents. The latest paper is by Axel Born,[3]

[1] Schmidt. Untersuchungen über die silurische formation von Ehstland, Nord-Livland und Oesel. Archiv. fur naturk. Liv-, Est-, und Kurlands, 1858, ser. 1, **2**, p. 1–248, 465–475.

[2] Bassler. The early Paleozoic Bryozoa of the Baltic Provinces. Bull. 77, U. S. N. M., 1911.

[3] Born. Centralbl. min. geol. pal., 1913, no. 22, p. 712–720.

who takes exception to some of Bassler's conclusions relating to the stratigraphy. A work which discusses the history, archaeology, stratigraphy, and natural history of the Russian Baltic provinces appeared in Riga in 1911, and bore the title, Baltische Landeskunde. It was the work of several writers, that which pertained to the Palaeozoic geology having been written by A. von Mickwitz. It is a good work for general reference.

Introductory discussion of the Esthonian section. The entire sequence of the Russian Baltic section consists of evenly bedded, almost horizontal limestones and subordinate shales with an occasional thin division of sandy material. There is a very gentle dip southwestward, generally imperceptible. The entire Ordovician and Silurian may have a thickness of 725 feet, of which about 350 feet are Ordovician and 375 feet Silurian.

Natural outcrops are not common, rarely existing save at the seashore, where the Cambrian and basal divisions of the Ordovician are exposed in the cliffs, or, as they are called in Esthonia, glints. On the island of Oesel the Silurian is exposed in the sea cliffs, which on this island are known as panks. Had one to depend on natural exposures little could be learned of the stratigraphy of the land a few miles distant from the sea. Everything is grassed over and, if a surface be made bare, a few years suffice to completely cover it again. Fortunately, however, the need of limestone for burning or construction purposes in the past, led to the opening of many small quarries, and in later times artificial exposures have been further increased by the digging of ditches for the drainage of swamps or roads. Through these, a partial understanding of the stratigraphy of the interior has been attained. Of late years the demand for lime and stone appears to have decreased, or to have been supplied from elsewhere, since many of the quarries studied by Schmidt are now wholly or partially grassed over, so that their examination is difficult, and, in some cases, impossible. Large cement plants have been built at Port Kunda and Asserian, and these have developed extensive exposures of the lower divisions of the Ordovician; but nothing of the higher beds.

Up to the present it has been impossible to learn the exact sequence of strata above the Echinosphaerites limestone and it is rare that one is able to discover the contact of any formation with those adjacent. Hence the determination whether certain strata are continuous with others, from which they differ through horizontal variation of sediments, or whether they lie at a different horizon, has not been possible. It will probably be long before the sequence is completely known.

To some of the divisions, geographical formational names were applied by Schmidt, while others were named after some characteristic fossil or lithic characteristic. Each division coming within the writer's problem has been redefined, Schmidt's geographical terms have been retained, with, so far as determinable, the limitations imposed by him. To divisions named after characteristic fossils, geographical formational names have been applied.

The names of the fossils listed have been taken from Schmidt, Koken, Bassler, and others, and some are field identifications.

THE ORDOVICIAN SYSTEM.

Introduction. The Ordovician was subdivided by Schmidt into the following members which are named with their thicknesses (approximate only) from the summit downward.

F2.	Borkholm limestone.	20 ft.
F1.	Lyckholm limestone.	50–60 ft.
E.	Wesenberg limestone.	30 ft.
D3.	Wassalem limestone.	10 ft.
D2.	Kegel limestone.	10 ft.
D1.	Jewe limestone.	100 ft.
C3.	Itfer beds.	10 ft.
C2.	Kuckers shale.	10 ft.
C1.	Echinosphaerites limestone.	30 ft.
B3.	Vaginaten limestone.	10 ft.
B2.	Glauconite limestone.	30 ft.
B1.	Glauconite sandstone.	30 ft.

Of these only the Lyckholm and Borkholm limestones come within the writer's problem.

Lyckholm formation. The most easterly known exposures of this formation are along the lower course of the Pungern Brook just before it empties into the northern end of Lake Peipus. Bending northward the outcrops follow just north of the 59th parallel, and reach the sea on the Nuckö peninsula, north of the city of Hapsal. The Island of Worms probably belongs wholly to the Lyckholm and there are extensive outcrops on the northern side of Dago. The thickness of the formation is not known exactly, but it is estimated to be about fifty or sixty feet.

The division received its name from Lyckholm, the home of Baron Rosen, which is situated on the long Nuckö peninsula, opposite the city of Hapsal. The type-exposure, and apparently the only one in the vicinity, lies about one eighth of a mile north of the dwelling. Formerly it was quite extensive, but at present little is shown and the old dump heaps have been picked over so frequently, that, without further quarrying, it is now impossible to obtain a representative collection. The rock consists of gray and white to yellowish white, rather thick-bedded, partially crystalline limestone, the individual beds being separated by thin shale partings. Not more than five or six feet are, or were exposed. It appears very probable that these beds belong to the lower division of the formation.

Several small exposures have recently been developed at Hohenholm on the Island of Dago and from five to six feet of strata have been exposed, consisting of blue and gray limestone with thin shale partings. The bedding is not well defined. The Kegel appears to lie about five or six feet below the surface, and it seems to be visible at the water's edge a short distance north, and just back of the factory at Hohenholm, a ditch reaches a limestone of Kegel aspect, and so Dr. Raymond considers it. Schmidt reports the occurrence of the Wesenberg limestone on the shore by the village of Rootsi, only a short distance east [1] but what he saw was probably the Kegel. The older Hohenholm exposures could not be found. These beds contain essentially the same fauna as those at Lyckholm; *Halysites catenularia*, the typical *Porambonites gigas*, and *Triplecia insularis*, in addition to other fossils, having been collected.

At Paope, about four miles southwest of Hohenholm, is a quarry of considerable size which during the summer of 1914 was being worked. Not over six or seven feet of rock are exposed, consisting of soft impure bluish gray limestone of semicrystalline texture with beds of blue shale separating the limestones. The beds of this quarry probably lie a little above those of the Hohenholm exposures, as the locality is south of that place and the quarry is situated on a little higher ground. The fauna is the same as that of Lyckholm and Hohenholm and the lithology is also quite similar. Fossils are very abundant.

Kertel is the name of a village on the northern side of Dago and the quarries are located about a mile south of the village, near Palloküll Krug (Plate 2, fig. 1).[2] About six feet of somewhat heavy-

[1] Schmidt. Loc. cit., 1858, p. 136.

[2] A krug is a place where lodging and food may be obtained.

bedded, semicrystalline, grayish blue limestones and thin shales are exposed. Throughout most of the thickness the bedding is illy defined. Some of the beds are quarried for construction purposes and these are from four to six inches thick. The basal beds are more shaly than those above and locally consist of 50% shale. The limestone is similar to that of the other localities mentioned above.

At Pallokull Chapel, three to four miles south of Kertel, on the road to Helterma, is an exposure of what appears to be the Kegel. The outcrop is in the woods a short distance back of, and southwest of the chapel, and the beds dip from ten to fifteen degrees northward. Unless the tilting of the Kegel is purely local and involves the higher beds, it follows that the Lower Lyckholm rests unconformably on the former. That the relations are disconformable appears fairly certain.

Another exposure of what appears to be the Lower Lyckholm was seen at Kappa-Koil, south of Reval, on the railroad to Pernau; but the old quarry was almost wholly grassed over and no fossils were collected.

Near Muddis Krug, about two miles east of the railroad station, Taps, is an outcrop of the Lyckholm which is of considerable importance as the exposed beds are not far above the contact with the Wesenberg and the locality is nearly at the eastern end of the Silurian territory. A long low cutting on the railroad about a mile and a half east of Taps exposes a dense fine-grained, almost unfossiliferous limestone. In a small quarry nearer Taps, beds of a similar character are exposed in which *Chasmops wesenbergensis* and a few other fossils were collected which show the strata to belong to the Wesenberg.

About a half mile south of the railroad cutting and a half mile west of the Meinkerb residence is the old quarry referred to by Schmidt as "near Muddis Krug." Only two feet of irregularly bedded, whitish earthy limestone are now visible. The fauna from these beds consists of such typical Lyckholm forms as *Porambonites gigas*, *Pseudolingula quadrata*, *Triplecia insularis*, Halysites, Heleolites, and large gastropods of the genera Hormotoma and Subulites, forms essentially identical with those found in the Lyckholm beds on the Island of Dago at the locality where it overlies the Kegel, and they show that the lower beds of the formation are the same in the two widely separated regions.[1]

The strata described in the preceding paragraphs do not exceed

[1] For the information relating to the outcrops near Taps I am indebted to Professor Raymond.

twenty-five feet in thickness and all apparently belong to the Lower Lyckholm. The lowest beds seen appear to be those of Hohenholm and Taps.

The best present collecting localities for the lower divisions of this formation are Paope and Pallokiill, both on the island of Dago. At these two places the quarries are in operation and new exposures are constantly being made. Other localities in addition to those mentioned where the lower beds appear to outcrop are Neuenhof, Oddalem, Saximois, Sutlep, Forel, and Kirna.

Characteristic fossils of the Lower Lyckholm are *Pseudolingula quadrata, Porambonites gigas, Triplecia insularis, Subulites gigas,* and *Salpingostoma dilatatum.* The species which are known to occur in the lower portion of the Lyckholm are:—

1. Calapoecia canadensis Billings.
2. Clathrodictyon cf. vesiculosum Nicholson and Murie.
3. Columnaria fascicula Kutorga.
4. Halysites catenularia (Linné).
5. escharoides (Lamarck).
6. Paleofavosites asper (d'Orbigny).
7. Proheliolites dubius Schmidt.
8. Streptelasma cf. corniculum Hall.
9. Syringophyllum organum Linné.
10. Anaphragma mirabile Ulrich and Bassler.
11. Ceramopora intercellata Bassler.
12. Chilotrypa immatura Bassler.
13. Corynotrypa abrupta Bassler.
14. barberi Bassler.
15. dissimilis (Vine).
16. Dianulites colliferus Bassler.
17. grandis Bassler.
18. sulcatus Dybowski.
19. Dittopora colliculata (Eichwald).
20. Diplotrypa petropolitana Nicholson.
21. Glauconema plumula Wiman.
22. Hallopora elegantula (Hall).
23. Monticulipora dagoensis Bassler.
24. Nematopora fragilis Ulrich.
25. Orbignyella expansa baltica Bassler.
26. Orbipora fungiformis Eichwald.
27. Pachydictya bifurcata (Hall).

28. Ptilodictya flabellata Eichwald.
29. gladiola Billings.
30. Stellipora constellata Dybowski.
31. Stomotopora arachnoidea (Hall).
32. Atrypa imbricata Sowerby.
33. Clitambonites sinuatus (Pahlin).
34. verneuili (Eichwald).
35. Dalmanella elegantula estona (Wysogorski).
36. wimani Mickwitz.
37. Dinorthis solaris (von Buch).
38. Orthis actoniae Sowerby.
39. callactis Dalman.
40. concinna Lamansky.
41. flabellum Sowerby.
42. lyckholmensis Wysogorski.
43. oswaldi von Buch.
44. vespertilio Sowerby.
45. Platystrophia biforata lynx (Eichwald).
46. fissicostata (McCoy).
47. Plectambonites schmidti (Törnquist).
48. Porambonites gigas Eichwald.
49. Pseudolingula quadrata (Eichwald).
50. Rafinesquina deltoidea (Conrad).
51. Strophomena tenuistriata Sowerby.
52. Triplecia insularis (Eichwald).
53. Byssonychia cf. radiata (Hall).
54. Bucania contorta Eichwald.
55. cornu Koken.
56. crassa Koken.
57. cycloides Koken.
58. radiata (Eichwald).
59. Ectomaria kirnaensis Koken.
60. Eunema rupertre Eichwald.
61. sulcifera Eichwald.
62. schmidti, Koken.
63. Euomphalus carinifer Koken.
64. gradatus Koken.
65. laminosus Koken.
66. Holopea ampulacea Eichwald.
67. coronata Koken.
68. Isospira bucanoides Koken.

69. Lytospira valida Koken.
70. Murchisonia exilis Eichwald.
71. insignis Eichwald.
72. Pleurotomaria chamaeconus Koken.
73. nodulosa Schmidt.
74. notabilis Eichwald.
75. notlingi Koken.
76. numismalis Koken.
77. plicifera Eichwald.
78. rotelloidea Koken.
79. Pycnomphalus borkholmensis Koken.
80. Salpingostoma dilatatum (Eichwald).
81. Sinuites bilobatus (Sowerby).
82. Subulites bullatus Koken.
83. gigas Eichwald.
84. inflatus Eichwald.
85. subulus Koken.
86. Worthenia aista Koken.
87. esthona Koken.
88. silurica (Eichwald).
89. vermetus Koken.
90. Cyrtoceras sphynx Schmidt.
91. Discoceras antiquissimum (Eichwald).
92. Orthoceras arcuolyratum Hall.
93. Arges wesenbergensis Schmidt.
94. Calymene stacyi Schmidt.
95. Chasmops eichwaldi Schmidt.
96. Cybele brevicauda Angelin.
97. Encrinurus multisegmentatus Portlock.
98. seebachi Schmidt.
99. Goldius laticaudus (Wahlenberg).
100. Harpes wegelinus Angelin.
101. Homolichas angustus (Beyrich).
102. Illaenus angustifrons Holm.
103. caecus Holm.
104. linnarssoni Holm
105. mascki Holm.
106. roemeri Volborth.
107. Platylichas hamatus Schmidt.
108. laxatus McCoy.
109. Amphilichas laevis Eichwald.
110. lineatus Schmidt.

111. Prionocheilus pedolobum (F. Roemer).
112. Proetus kertelensis Schmidt.
113. ramisulcatus Nieszkowski.
114. Remopleurides emarginatus Tornquist.
115. Sphaerexochus angustifrons Angelin.
116. Sphaerocoryphe cf. granulata Angelin.
117. Trinucleus seticornis Hisinger.

From some portion of the Lyckholm, and perhaps the lower part, were derived the species whose names follow: —

1. Aulocoporella cepa (Roemer).
2. Aulocopodium aurantium Oswald.
3. Cyclocrinites spasski Eichwald (very doubtful).
4. Solenopora spongioides Dybowski.
5. Acantholithus astericus Roemer.
6. Alveolites? hexagona Schmidt.
7. Coccoseris micraster Lamansky.
8. ungerni Eichwald.
9. Halysites parallellus Schmidt.
10. undulatus Kiaer.
11. Heleolites hirsutus Lamansky.
12. inordinatus Sowerby.
13. interstinctus Linnaeus.
14. parvistellus Roemer.
15. Labechia conferta Edwards and Haime.
16. Lyellia bacillifera Lamansky.
17. conferta Edwards and Haime.
18. tubulata Edwards and Haime.
19. Petraia darcoceras Dybowski.
20. silurica Dybowski.
21. Protaraea cf. vetusta Hall.
22. Streptelasma europaeum Roemer.
23. Tetradium wrangeli Schmidt.
24. Glaphyrocystis compressa Jaekel.
25. wohrmanni Jaekel.
26. Hemicosmites grandis Jaekel.
27. verrucosus Jaekel.
28. Aulacomerella angusta Huene.
29. macroderma (Eichwald).
30. Craniella? papillifera Huene.

31. Dinobolus schmidti Davidson.
32. Eleutherocrania gibberosa Huene.
33. Orthis sadawitzensis Wysorgorski.
34. Pseudocrania cranoides Huene.
35. Pseudometoptoma concentricum Huene.
36. curvatum Huene.
37. monopleurum Huene.
38. Strophomena assmussi Verneuil.
39. luna Törnquist.
40. semipartita Roemer.
41. Modiola devexa Eichwald.
42. incrassata Eichwald.
43. Cymbularia aequalis Koken.
44. Murchisonia scrobicula Koken.
45. spectabilis (Schmidt).
46. Conularia cf. trentonensis Hall.
47. Tentaculites anglicus Salter.
48. Cyrtoceras angulosum Schmidt.
49. Endoceras hasta Eichwald.
50. Orthoceras cuneolus Eichwald.
51. exaltatum Eichwald.
52. fenistratum Eichwald.
53. ibex Eichwald.
54. Ceraurus cf. glaber Angelin.
55. Homolichas eichwaldi Nieszkowski.
56. Platylichas docens Schmidt.

The upper beds of the Lyckholm formation are best shown at Pirk (Plate **2**, fig. 2) and Saremois, the former about three miles northwest of Herküll and the latter hardly more than a mile in the same direction. Pirk consists merely of a watermill and a few houses and the exposure is in a small cliff on the right bank of the creek, just below the mill-dam. About nine feet of yellowish white and white limestones of a somewhat chalky or marly consistency are shown, the sequence consisting of alternations of slightly different varieties of the same kind of rock and the whole having a somewhat massive appearance with illy defined bedding. Through sun and frost action it spalls off with conchoidal fracture. Fossils are quite common, corals comparatively rare, large gastropods are the most abundant and the Maclureas were collected near the base.

Between Pirk and Kappa-Koil, at various localities on the higher

lands and from one to five miles from the latter place, are outcrops of thick-bedded dolomitic limestone with very poorly preserved fossils and these chiefly corals. These strata may lie between the Lower Lyckholm of Kappa-Koil and the strata of Pirk, or may be some division of the Borkholm.

The exposures at Saremois, a part of the Herküll estate, are quite extensive, occurring in ditches which have been crisscrossed over a tract of about forty acres. Most of the ditches are excavated through alluvium, but in many places what appear to be buried knolls of the country rock have been cut through. The lithology and fauna are the same as at Pirk; but the strata are thought to be from ten to fifteen feet higher in the section and they must lie almost immediately below the lowest beds of the Borkholm formation, as the latter outcrop in the woods between Herküll (about a mile southeast) and Saremois, and the vertical distance between the two outcrops amounts to but a few feet. Corals are quite common at Saremois, while rather rare at Pirk, due probably to the small size of the exposure at the latter place.

Strata with a lithology and fauna similar to that above described also occur near the village Rannaküll, about six miles northeast of Hapsal. Thin bands of gray shale separate the four to six inch beds of yellowish white, somewhat marly-like limestone.

From these different localities have been collected the species whose names follow. Those which are not followed by the authority also occur in the Lower Lyckholm: —

1. Clathrodictyon cf. vesiculosum.
2. Halysites catenularia.
3. Paleofavosites asper.
4. Syringophyllum organum.
5. Dianulites grandis.
6. Diplotrypa petropolitana.
7. Graptodictya obliqua Bassler.
8. Atrypa imbricata.
9. Orthis actoniae.
10. flabellum.
11. Platystrophia biforata lynx.
12. Rafinesquina deltoidea.
13. Byssonychia cf. radiata.
14. Bucania cornu.
15. crassa.
16. radiata.

17. Eunema (?) piersalense Koken.
18. Holopea ampulacea.
19. Maclurea neritoides Eichwald.
20. Murchisonia insignis.
21. Subulites subulus.
22. Worthenia aista.
23. Cyrtoceras sphynx.
24. Discoceras antiquissimum.
24a. Arges wesenbergensis.
25. Chasmops eichwaldi.
26. Cybele brevicauda.
27. Encrinurus multisegmentatus.
28. Goldius laticaudus.
29. Harpes wegelinus.
30. Homolichas angustus.
31. Illaenus angustifrons.
32. linnarssoni.
33. roemeri.
34. Isotelus platyrachis Steinhardt.
35. robustus Roemer.
36. Platylichas laxatus.
37. Proetus ramisulcatus.
38. Pseudosphaerexochus conformis.
39. roemeri Schmidt.
40. Sphaerocoryphe cf. granulata.

Out of the total of forty species there are but seven which do not occur in the Lower Lyckholm and, so far as has been determined from the field-study, the fauna is the same as that of the lower beds as displayed at Lyckholm, Hohenholm, Palloküll and Paope.

From glacial boulders on Gotland Dr. Carl Wiman has collected fossils of Lyckholm age.[1] These boulders were no doubt derived from strata outcropping beneath the Baltic and with the boulders of Lyckholm limestone were others from the Borkholm. He has collected the following Esthonian Lyckholm fossils, of which some, however, may have come from Borkholm limestones:—

1. Acantholithus astericus.
2. Halysites catenularia.
3. escharoides.
4. parallelus.

[1] Wiman. Bull. Geol. inst. Univ. Upsala, 1902, **5**, pt. 2, no. 10.

5. Lyellia bacillifera.
6. Proheliolites dubius.
7. Atrypa imbricata.
8. Clitambonites sinuatus.
9. verneuili.
10. Dalmanella wimani.
11. Orthis oswaldi.
12. Platystrophia biforata lynx.
13. Strophomena assmussi.
14. semipartita.
15. Chasmops eichwaldi.
16. Isotelus robustus.
17. Proetus ramisulcatus.

Dr. Bassler from his faunal studies of Baltic Russian strata stated that it appeared very probable that a great time break exists within the Lyckholm formation, and "that the Wesenburg and early Lyckholm show affinities with the early Trenton, and that the upper Lyckholm and Borkholm closely resemble certain divisions of the Richmond group."[1] He describes the Lower Lyckholm as a "Magnesian limestone holding Maclurea, Subulites and other gastropods related to American Trenton species"[2] and "The bryozoans of the lower Lyckholm are, like those of the American Galena, distinctly Trenton in character." In his table of correlation he places the Lower Lyckholm as the equivalent of the Stewartsville dolomite of the Mississippi Valley.[3] In drawing his conclusions Bassler labored under the extreme difficulty of never having seen the strata in the field and he also had to accept the statements on the labels attached to the specimens which he studied.

Born[4] dissents from the conclusion of Bassler relating to a time break in the Lyckholm and denies its existence. He also disagrees with Bassler on the correlation of the Lyckholm; but as he fails to definitely state its stratigraphic equivalent in the American section, referring it to two possible horizons, this objection need not be further considered. Schmidt[5] described the Lower Lyckholm as a white, thick-bedded limestone, rich in silica and carrying few corals; while

[1] Bassler. Bull. **77**, U. S. N. M., 1911.
[2] Bassler. Loc. cit., p. 9.
[3] Bassler. Loc. cit., p. 17, 38.
[4] Born. 1913, Centralbl. min., geol., pal., 1913, no. 22, p. 714–19.
[5] Schmidt. Mem. Acad. sci. St. Petersb., 1881, ser. 7, **30**, no. 1, p. 37.

the upper part is a gray marly limestone which in places is full of corals. Either division is readily distinguishable from the Wesenberg (Schmidt states that the Lower Lyckholm resembles the Wesenberg), for the latter is far more hard, more compact, and finer grained and partakes more of the aspect of a lithographic stone. I dissent from the general statement of Schmidt that few corals occur in the Lower Lyckholm. Locally they are not uncommon, but there are not nearly so many as in the Upper Lyckholm and the Borkholm.

Bassler apparently was misled by the labels accompanying his specimens in considering that the Lower Lyckholm is characterized by Maclurea and Subulites and in respect to the gastropods, he appears to have reversed the sequence. Maclurea may occur in the Lower Lyckholm; but I have not seen it there, while it is common in the Upper Lyckholm. Subulites and large Hormotomas range throughout, but the latter are more abundant in the upper beds. In seeking for equivalents in American deposits, it is my judgment that no correlative value can be placed on these large gastropods of general Middle Ordovician aspect. Bassler now agrees in this view, for since his correlation of the supposed Lower Lyckholm he has learned of numerous examples of the reappearance of faunas, and of the close resemblance of the North American Black River and early Trenton faunas to those of the Richmond.

Although Bassler placed considerable emphasis on the Bryozoa in drawing his deductions relating to a time break, he appears to have relied more on the general aspect of the fauna. In respect to the Bryozoa it would be well to review those forms which he had in mind as indicative of Middle Ordovician time; these are *Corynotrypa barberi, Diplotrypa petropolitana, Dittopora colliculata, Stellipora constellata,* and *Stomotopora arachnoidea.* Each of these species is said to occur at Hohenholm, of which the present exposures are quite certainly the Lower Lyckholm and such was probably true of the older ones as the topography does not lend itself to the view that strata much higher than those now shown were formerly exposed. *Dittopora colliculata* and *Diplotrypa petropolitana* also occur at Pallokiill and the latter at Paope; but as they occur at these latter localities with at least thirteen other species of the Lyckholm Bryozoa, considered as evidence of "Silurian affinity," it follows that they must almost wholly be neglected as evidence of age. *Diplotrypa petropolitana,* moreover, is so long ranging that it has hardly any stratigraphic value. *Corynotrypa barberi* and *Stomotopora arachnoidea* occur at Hohenholm growing on Richmondian and Silurian corals

and *Ptilodictya flabellata* from the same locality is referred by Bassler to the Borkholm.

Since it is really the lower beds which contain nearly all the Bryozoa described by Bassler and few are from the upper beds, it must be inferred that Bassler's conclusion in so far as it relates to a time break arose from a mislabeling of the specimens as to stratigraphic position, and he "now agrees that not only the Upper Lyckholm is of Richmond age, as stated in his work, but that the Lower Lyckholm also should be so correlated."[1]

It appears very probable that the Lyckholm rests on the Wesenberg or the Kegel in apparent conformability, although the Pallokull Krug and Pallokull Chapel occurrences throw some doubt on this conclusion. There is, however, a sharp lithic and a considerable faunal change in passing from the Wesenberg to the Lyckholm. Of the great array of Lyckholm corals there is nothing seen in the Wesenberg.

The species whose names follow are common to the Lyckholm and underlying strata; but many of the gastropods and some of the other Lyckholm forms are varietally different. The letter following the name of a species refers to the name of the underlying formation in which the species occurs. (See p. 293).

1.	Cyclocrinites spasski	K.
2.	Dittopora colliculata	W.
3.	Diplotrypa petropolitana	W.
4.	Stomotopora arachnoidea	E. Ku.
5.	Plectambonites sericeus	W.
6.	Porambonites gigas	W.
7.	Rafinesquina deltoidea	W.
8.	Strophomena assmussi	J. K. W.
9.	Bucania contorta	W.
10.	cycloides	W.
11.	radiata	W.
12.	Isospira bucanoides	W.
13.	Murchisonia exilis	W.
14.	insignis	W.
15.	Pleurotomaria notabilis	W.
16.	Sinuites bilobatus	W.
17.	Subulites inflatus	W.

[1] Personal communication.

18.	Subulites subulus	W.
19.	Worthenia esthona	Ku. I.
20.	silurica	V. E. Ku. I. J. K. W.
21.	Arges wesenbergensis	W.
22.	Cybele brevicauda	W.
23.	Encrinurus multisegmentatus	W.
24.	seebachi	W.
25.	Homolichas eichwaldi (not certain as to its occurrence below).	
26.	Illaenus linnarssoni	W.
27.	roemeri	W.
28.	Prionocheilus pedolobum	W.
29.	Sphaerexochus angustifrons	W.

This is about fifteen per cent of the Lyckholm fauna, but several of the species are long ranging and, hence, have no stratigraphic value; most of the gastropods and some of the other forms are said to be varietally different, and in the case of a few (*Cyclocrinites spasski*) the identifications are uncertain. The number of common species of chronologic value, therefore, becomes small, and these must probably be looked upon as survivals from the older stage, as similarly occurs in the Richmond of America, and the difference between the Lyckholm and Wesenberg faunas argues for a time break of considerable importance, but one that does not appear to be of systemic value.

Borkholm formation. The eastern limits of this formation are near Lake Peipus, the strata making their first appearance at the surface near Pastfer and Müntenhof. Thence the outcrops of the formation extend westward over a narrow band just south of the 59th parallel. A few exposures, as the Nyby outlier, occur in Lyckholm territory. Except for the little island of Wohhi to the east of Dago,[1] the formation does not appear to have been noted on the islands. The division is probably not over twenty feet thick. The type-locality is in the park at Borkholm, the estate of Herr von Rennenkampf. The type-exposure is in a quarry, now no longer worked. According to Schmidt, there were formerly about fifteen feet of strata shown; but the present exposures are probably not so good as in earlier days, since little more than twelve feet are now uncovered and few fossils other than corals are obtainable.

The lowest beds are said to consist of a crinoidal limestone with a thickness of about a foot. Above this lies a coarse-grained, yellowish gray and white limestone which appears to contain few fossils other

[1] Schmidt. Bull. Acad. sci. St. Petersb., 1881, ser. 7, **30**, no. 1, p. 39.

than corals. Brownish limestones with thin calcareous shale partings succeed and at the top is a coral limestone, made up almost wholly of these organisms. This coralline limestone, according to Schmidt and Mickwitz, affords an excellent datum plane, which can readily be followed throughout the entire district. Eastward it is said to undergo dolomitization. About a mile west is a new quarry which during the summer of 1914 was in operation, and where fossils are more readily obtained. The lithology is about the same as the middle portion of the Borkholm section and about six feet are exposed.

Near Herküll, northwest of the dwelling and on the east side of the post road, is a small quarry in the Borkholm. Here the basal exposures consist of a fossiliferous, crystalline gray limestone with mammillary upper surface. Then follow fifteen inches of black shale, containing fucoidal impressions, and above this three feet of crystalline, coralline, and crinoidal limestone with many poorly preserved coral heads. The beds of this limestone are from two to ten inches thick.

The Herküll locality made known by Schmidt lies southwest of the dwelling, and the former exposures were made by a drainage ditch. At the north end of this ditch Schmidt noted the occurrence of the white Borkholm limestone in place. This is overlain by what appear to be thin-bedded limestones and shales which carry an abundance of fossils. No rock is visible in place, but the debris from the ditch has been stirred by plowing and the fossils are readily collected. Both fauna and lithology are similar to that of the locality described in the next paragraph. Schmidt further stated that the contact between the Silurian (Jörden Schicht) and the Borkholm could be seen here, the Jörden strata appearing at the top of the ditch near its midlength. Nothing of this is now visible.

The Nyby exposures, north of Hapsal, are the best that were seen of the Borkholm formation. The quarries are situated on a low terrace north of the residence of the Nyby estate, and are readily found by their nearness to an old stone windmill.

The section exposed in these quarries, given from the summit downwards, is as follows: —

1. Impure, dark gray, semicrystalline limestone in four to six inch beds, separated by thin beds of gray shale. In places 50% of the limestone consists of the stems of large crinoids. Four feet six inches.

2. Impure, dark gray, poorly crystalline limestone (beds four to six inches thick) and thinner beds of gray calcareous shale. Two feet.

Fossils are extremely common throughout, particularly corals

belonging to the Heleolitidae, Calapoecia, Favosites, and Halysites. Bryozoa are very abundant and there are also many brachiopods.

The fauna of the formation is as follows: —

1. (?) Aulocopodium aurantium.[1]
2. Acanthodus tubulus Dybowski.
3. Acantholithus astericus.
4. Calapoecia canadensis.
5. Clathrodictyon cf. vesiculosum.
6. Coccoseris microporus Eichwald.
7. Coelophyllum amalloides Dybowski.
8. Columnaria fascicula.
9. Cyathophyllum middendorfi Dybowski.
10. Endophyllum contortiseptum praecurser Weissermüll.
11. Favosites forbesi Milne Edwards.
12. Halysites catenularia.
13. escharoides.
14. parallelus.
15. undulatus.
16. Heleolites inordinatus.
17. Lyellia bacillifera.
18. cancellata Lamansky.
19. conferta.
20. Paleofavosites asper.
21. Pholidophyllum tubulatum Schlotheim.
22. Streptelasma elongatum Phillips.
23. europaeum.
24. Syringophyllum organum.
25. Hemicosmites tricornis Jaekel.
26. Chasmopora tenella (Eichwald).
27. Corynotrypa dissimilis.
28. Fenestella striolata Eichwald.
29. Glauconema plumula.
30. strigosa (Billings).
31. Hallopora elegantula.
32. Lichenalia concentrica Hall.
33. Nematopora lineata (Billings).
34. Pachydictya bifurcata.
35. Phaenopora ensiformis (Hall).

[1] Species without authority also occur in the Lyckholm.

36. Protocrisina exigua Ulrich.
37. Pseudohornera orosa (Wiman).
38. Ptilodictya gladiola.
39. Sceptropora facula Ulrich.
40. Atrypa imbricata.
41. marginalis Dalman.
42. cf. nodostriata Hall.
43. undifera Schmidt.
44. Clitambonites sinuatus.
45. verneuili.
46. Discina gibbi Lamarck.
47. Eleutherocrania gibberosa.
48. Leptaena rhomboidalis (Wilckens).
49. Orthis actoniae.
50. oswaldi.
51. sadawitzensis.
52. Platystrophia biforata lynx.
53. Plectambonites schmidti.
54. sericeus (Sowerby).
55. Pseudocrania cranoides.
56. Pseudometoptoma concentricum.
57. monopleurum.
58. Streptis sp.
59. Strophomena expansa Sowerby.
60. luna.
61. tenuistriata.
62. Triplecia insularis.
63. Byssonychia cf. radiata.
64. Ectomaria nieszkowski Koken.
65. Eunema rupestre.
66. schmidti.
67. Euomphalus dimidiatus Koken.
68. gradatus Koken.
69. helicoides Koken.
70. Helicotoma superba Koken.
71. Murchisonia meyendorfi Koken.
72. Pycnomphalus borkholmemsis.
73. Trochonema minor Koken.
74. panderi Koken.
75. peraltum Koken.
76. Tryblidium ėsthonum Koken.
77. lindströmi Koken.

78. Worthenia borkholmensis Koken.
79. tolli Koken.
80. Tentaculites annulatus Schlotheim.
81. Discoceras antiquissimum.
82. Orthoceras calamiteum Portlock.
83. Calymene stacyi.
84. Encrinurus multisegmentatus.
85. Homolichas angustus.
86. Illaenus angustifrons depressus Holm.
87. roemeri.
88. Isotelus robustus.
89. Platylichas cicatricosus Loven.
90. margaratiferus Nieszkowski.
91. Proetus ramisulcatus.
92. Pseudosphaerexochus conformis.
93. roemeri.
94. Sphaerocoryphe cf. granulata.
95. Leperditia brachynoti Schmidt.

Other places in Esthonia where the Borkholm may be seen are Ruil and Pastfer in the east; and Nomküll, Kurro, Kerrofer, Affel, and Noistfer in the west.

On Gotland Wiman obtained from glacial boulders scraped by ice from Borkholm limestones, which probably lie beneath some parts of the Baltic, the following Esthonian species:—

1. Acantholithus astericus.
2. Favosites forbesi.
3. Halysites catenularia.
4. escharoides.
5. parallelus.
6. Lyellia bacillifera.
7. Glauconema plumula.
8. Rhinidictya borkholmensis.
9. Atrypa imbricata.
10. undifera.
11. Clitambonites sinuatus.
12. Dalmanella wimani.
13. Leptaena rhomboidalis.
14. Orthis oswaldi.
15. Platystrophia biforata.
16. Chasmops eichwaldi.

17. Isotelus robustus.
18. Platylichas cicatricosus.
19. Proetus ramisulcatus.

Stratigraphic and Faunal Relations of the Borkholm Formation to the Lyckholm.

There are no reasons for believing that the Borkholm is other than conformable on the Lyckholm and directly continuous thereto. Furthermore, the faunas are essentially identical and at least fifty-three of the ninety-five Borkholm species occur in the Lyckholm. Several of these common species belong to the genus Halysites. I believe it will ultimately be found necessary to unite several of these; but this will not change the strong faunal similarity. Each formation contains many species of Silurian aspect; this is shown to a greater degree in the Borkholm, where Silurian forms are conspicuous and abundant, but the Ordovician expression dominates.

Time Equivalents of the Lyckholm and Borkholm.

At present these can be given in only a general way. When the collections have been secured and submitted to a careful study it is hoped to give a detailed correlation.

Considered as a whole the faunas bear an aspect not generally familiar to American stratigraphers. The large Porambonites; the association of Halysites and members of the Heliolitidae with large Hormotomas, Maclureas, and Subulites; and the abundance of large Triplecias are faunal groupings not occurring in America, yet certain associations are similar and the faunas have many components which are present in American deposits, the writer being constantly impressed with certain striking similarities.

The points of contact with American sections are greatest in number in the Anticosti formations,[1] where the facies and faunal associa-

[1] The Anticosti section is, figuratively speaking, on the frontier of the American Upper Ordovician and Silurian, and hence would be most likely to show the greatest faunal similarities to the strata of like age of northwestern Europe. The Anticosti section consists of eight formations of which the lower four are Ordovician and the upper four Silurian. Named from the summit downward, the formations are as follows.

Silurian	Chicotte.	Ordovician	Ellis Bay
1223 feet	Jupiter River.	939 feet.	Charleton
	Gun River.		English Head
	Becsie River.		Macasty.

tions are quite similar to those of Esthonia. The faunal elements common to the two regions, however, are not so many as one could wish.

A correlation is most readily made if the Borkholm formation be taken as a point of departure. It has its closest faunal relations with the Ellis Bay formation of the Anticosti section, where are found the following identical or closely related forms:—

1. Calapoecia canadensis.
2. Clathrodictyan vesiculosum.
3. Halysites catenularia.
4. Paleofavosites asper.
5. Protaraea vetusta (this form in Esthonia occurs in the Lyckholm only).
6. Zaphrentis affinis (a similar form in the Borkholm is called Streptelasma elongatum).
7. Corynotrypa dissimilis.
8. Hallopora elegantula, var. nov.
9. Glauconema strigosa.
10. Nematopora lineata.
11. Phaenopora ensiformis.
12. Protocrisina exigua (Charleton, not Ellis Bay).
13. Ptilodictya gladiola.
14. Sceptropora facula (Charleton, not Ellis Bay).
15. Stomotopora arachnoidea (not in Borkholm, but Lyckholm).
16. Atrypa marginalis.
17. Clitambonites verneuili diversus (Shaler).
18. Platystrophia regularis Shaler (European type with two plications in the sinus and three on the fold).
19. Leptaena rhomboidalis.
20. Pseudolingula elegantula (Shaler) (P. quadrata in the Lyckholm).
21. Plectambonites sericeus.
22. Byssonychia sp. nov.
23. Calymene meeki Foerste.
24. Encrinurus multisegmentatus.

This constitutes a total of twenty-four out of ninety-five species, over twenty-five per cent of the Borkholm fauna, and coupled with this, is the further fact that each witnesses the occurrence in great numbers of a multitude of tabulate corals of Silurian aspect, which in

each region make their first appearance in significant numbers in the underlying formation. Considering that the Borkholm fauna has not been carefully studied for correlation with North America, the common occurrence of such a great number of species is rather remarkable. If only the Bryozoa be considered it is found that eight of the fourteen Borkholm species are also found in the Anticosti section, six in the Ellis Bay and two in the Charleton. It is therefore probable that when other phyla have been subjected to as careful comparative study as have the Bryozoa, that a greater number of species will be found common to the two regions. Since not so close faunal contact or general expression is shown with any other Anticosti formation, it is held as extremely probable that the Borkholm represents the whole or a part of the Ellis Bay formation. The Lyckholm, hence, represents some part of the Charleton formation. Large Subulites and Hormotomas are found in the upper part of this formation in association with Halysites and members of the Heliolitidae. There are, however, no Maclureas. Common or similar species are as follows:—

1. Calapoecia canadensis.
2. Halysites catenularia.
3. Paleofavosites asper.
4. Streptelasma rusticum Billings (S. corniculum is said to occur in Esthonia).
5. Zaphrentis affinis.
6. Corynotrypa dissimilis.
7. Nematopora lineata.
8. Protocrisina exigua.
9. Sceptropora facula (Borkholm).
10. Clitambonites verneuili diversus.
11. Plectambonites sericeus.
12. Pseudolingula elegantula.
13. Byssonychia sp. nov.
14. Sinuites cf. bilobatus.
15. Calymene meeki.
16. Proetus alaricus Billings.

Formerly I was inclined to believe that the Lyckholm and Borkholm found their equivalents in the lower parts of the Ellis Bay and the English Head and Charleton formations.[1] This view is now modified as stated above and it is believed that the English Head and perhaps

[1] Twenhofel. Bull. 3, Victoria memorial museum, 1914, p. 19.

the Lower Charleton do not find representation in the Esthonian section, since the English Head formation appears younger than the Wesenberg and older than any part of the Lyckholm.

If the views previously expressed [1] as to the chronologic position of the Ellis Bay formation be correct, it follows that the correlation of the Borkholm with the Ellis Bay formation leads to the conclusion that the former is not represented in the known deposits of the North American Interior. As the Charleton formation is certainly the equivalent of the Richmond beds of the Interior, the conclusion follows from the above correlation that the Lyckholm beds are of Richmond age, and such the writer considers them, referring them with little doubt to the upper portion of that formation. It may be noted that Bassler correlated the Upper Lyckholm and the Borkholm with the Richmond which he considers of early Silurian age. In the latter view I can not follow him.

These two divisions have repeatedly been correlated with the Leptaena kalk and Brachiopod shales of Sweden and the Gastropoden kalk and Meristella crassa zone of Norway and I now see no reasons for dissenting from this view. Correlation has also been made with the Caradoc or Bala of the British Isles, but detailed work is necessary to determine the exact position. Its closest relations appear to be with the Keisley limestone of northwestern England and the Chair of Kildare limestone of Ireland.

THE SILURIAN SYSTEM.

Introduction. The most easterly observed occurrence of the Silurian strata of Esthonia is near the village Pastfer to the northwest of Lake Piepus. It thence extends westward, south of Herküll and Hapsal, forming the surface rock of the south end of Dago and the whole of Moon and Oesel. On the mainland its outcrop forms a strip about 40 miles wide from north to south.

Except that there is no appreciable departure from parallelism of bedding, the stratigraphic relations of the lowermost division of the Silurian to the Borkholm formation are not known. At no place was the contact with the Ordovician seen. According to Schmidt, a contact was formerly visible at Herküll, but at present there is no

[1] Twenhofel. Loc. cit., 1914.

exposure of the lower beds of the Silurian at that place. As will be shown later, however, there is an extensive time break at the base of the Silurian.

The lithology of the Silurian is somewhat different from that of the Ordovician, in that there is a greater degree of dolomitization of the limestones, coralline limestone constitutes a larger proportion of the rock, and, except in the higher beds, shales are far less conspicuous.

The faunas are quite different. The corals in many species are the same as those of the Ordovician and some of the Borkholm Bryozoa also appear to cross the system boundary; but the gastropods, pelecypods, cephalopods, brachiopods, and trilobites are almost altogether different.

One can hardly fail to escape the conclusion that the Silurian deposits of Baltic Russia are those of quite shallow water and near a shore. The horizontal variation of sediments, the extensive reef deposits made by animals which must certainly have lived near the surface, and the masses of shell breccia, as in the Borealis banks, can hardly lead to another view. If this view be correct it follows that there should be considerable horizontal lithic variation and this appears to obtain.

There are certain features of the faunas which are of interest. These features arise from the fact that common species of other parts of the Baltic are not found in Russia. The lowest beds of Gotland, just a short distance away, are characterized by an abundance of *Stricklandinia lirata* (Sowerby), while *Bilobites bilobus* (Linné) of slightly higher beds is an equally abundant Gotland fossil. *Coelospira hemispherica* (Sowerby), is a common Middle Llandovery species of the Kristiana region of Norway and of England and it also is not found in the Silurian of Esthonia.

It is not clear how the absence of these species is to be explained. One explanation would be that the equivalents of the Gotland beds containing *Stricklandinia lirata* and *Bilobites bilobus* were never deposited in Baltic Russia, and that beds are also absent which are the equivalents of those of the Kristiana region of Norway carrying *Coelospira hemispherica*. Since the first two mentioned fossils belong to different horizons in the Gotland section, the above explanation leads to the assumption of two time-breaks in the Esthonian Silurian at the places where these fossils should be present; that is, somewhere within the Addifer and St. Johannis formations.

The preceding explanation is by no means satisfactory. Marine animals have their habitats determined by a combination of an extremely great number of varying conditions, and the absence of the

species mentioned may as well have been due to the absence of some of the conditions that were necessary for their presence. This explanation is in keeping with the fact that *Bilobites bilobus* is not universally distributed in the Gotland division in which it occurs, while in Norway Kiaer assigns it to different horizons in different facies.

The divisions of the Esthonian Silurian as determined by Schmidt [1] are as follows, the highest division being named first.

Upper Oesel zone, stage K or 8, thickness, 50–75 ft.
Lower Oesel zone, stage I or 7, thickness, 100 ft.
Pentamerus estonus zone, stage H or 6, thickness, 50 ft.

Raikull beds	stage G	substage	G3	or 5, thickness, 20 ft.
Borealis bank		"	G2	or 4, thickness, 10 ft.
Jörden beds		"	G1	thickness, 20–30 ft.

For these names the following are proposed: —

Oesel formation for stage K.
St. Johannis formation for stage I.
Addifer formation for stage H.
Tamsal formation for stage G.

There are several reasons why stage K. should be subdivided; but, as the outcrops are hardly sufficient to determine the exact sequence and the relation of the upper subdivision to the lower, it is considered wiser to leave the formation undivided. The matter will be further considered under the proper heading.

Tamsal formation. The three lowermost divisions of the Silurian were grouped together by Schmidt, and there appear to be no good reasons for changing the grouping. Where well defined, the Borealis Banks are worthy of distinction; but as these shells appear to enter into both the strata above and below, it would appear unwise to make a formational separation from either. At no place can the three divisions be seen together.

(a) *Jörden zone.* The Jörden zone makes its most eastward appearance just west of Lake Peipus and thence can be traced to the sea-coast a short distance south of Hapsal. Of the islands, Dago appears to be the only one on which it occurs. Since no section is known showing the contact with both the Borkholm and the succeeding Borealis banks, its thickness is quite uncertain. Schmidt [2] estimated that it may lie between twenty and thirty feet.

[1] Schmidt. Quar. journ. Geol. soc. London, 1882, p. 525.
[2] Schmidt. Loc. cit., 1882, p. 526.

The type-section of this zone is exposed in an old quarry near and across the road from Jörden church (Plate 3, fig. 1). Only about seven feet are shown. At the base are four feet of mottled gray and red dolomitic limestone and this is overlain by three feet of the Borealis bank. No fossils were seen in the Jörden strata at this point.

The zone was again seen about three fourths of a mile northwest of Tamsal and also southeast of that village. West of Tamsal about two feet are exposed and there is perhaps a little more in the woods to the southeast of the village. At Podrang, south of Tamsal, it is probable that the basal portion of the thirteen feet which are shown there may belong to the Jörden. The rock at these various places consists of a somewhat reddish, coarse-grained limestone which is not very fossiliferous.

The division was also seen near Hapsal on the Weisenfeld estate, about a mile west of the dwelling. The quarry is quite large and the exposures are particularly good. About six feet are exposed of which the lower three feet belong to the Jörden zone and consist of heavy-bedded (beds four to six inches thick) gray, crystalline limestone containing Favosites, Clathrodictyon, and rarely *Pentamerus borealis* Eichwald. Above lie three feet of thin-bedded, yellowish, semi-crystalline limestone which contains a great abundance of Favosites, species of the Heliolitidae, *Halysites catenularia*, Clathrodictyon, and entire and broken *Pentamerus borealis*. On the island of Dago the outcrop of Puhhalep probably belongs to this division. The exposure consists of from four to five feet of coarsely crystalline, thin-bedded (beds 1–3 inches), dolomitic limestone which contains little other than corals. Other outcrops on Dago are those of Grossenhof and Kallasto.

The fossils of this division are few in number and generally not well preserved. They have not yet been studied by the writer and the species listed with few exceptions are taken from others. Near the base is a small fauna which promises much of interest, but until carefully studied nothing will be said concerning it. Schmidt gives as the fossils most characteristic of the Jörden beds, the following species: —

1. Cyathophylloides kassariensis Dybowski.
2. Densiphyllum thomsoni Dybowski.
3. Donacophyllum losseni Dybowski.
4. schrencki Dybowski.
5. Favosites gothlandicus Lamarck.
6. Halysites agglomeratus Eichwald (= H. catenularia?).

7. Heliolites interstinctus.
8. Paleofavosites aspera.
9. Atrypa imbricata var.
10. Coelospira duboysi (Verneuil).
11. Dinobolus davidsoni Salter.
12. Orthis bouchardi Verneuil.
13. davidsoni Verneuil.
14. Rhynchonella aprinis Verneuil.
15. Schuchertella pecten (Linné).
16. Encrinurus punctatus Wahlenberg.
17. Proetus cf. distans. Lindström.
18. planedorsatus Schmidt.
19. Leperditia schmidti Kolm.

There have also been recognized *Clathrodictyon vesiculosum, Favosites forbesi, Halysites catenularia,* and *Pentamerus borealis.*

(b) *Borealis banks.* This is one of the most remarkable deposits of fossil shells I have ever seen. They are almost wholly *Pentamerus borealis,* generally single valves, although in the western outcrops it is possible to obtain entire shells.

Respecting the continuity of this zone it is not possible to speak with certainty; but the general facts of the distribution of marine organisms would lead to the conclusion that it is not of wide extent and it seems very probable that it thins westward. It also appears quite probable that in places the character of deposition which gave rise to the Jörden beds may have persisted upward while the shell-banks grew around, or within such places, that is, the banks are of a more or less local distribution.

The zone makes its first appearance west of Lake Peipus near St. Simon's church, and, narrowing toward the east, the belt of its outcrop reaches the coast a few miles south of the city of Hapsal, and finds its further continuation on the island of Dago. Schmidt, (*Loc. cit.,* 1882, p. 526) gives the thickness as forty feet.

Where the division is typically shown little else is to be seen other than myriads of *Pentamerus borealis* and a few corals. The number of the former is simply inconceivable. The rock is wholly a mass of the shells, which are chiefly preserved as casts. Where the shells are not the dominant component, the rock is either a limestone or a dolomite.

About the best locality to see this division, and the one which has been selected as the type-locality of the Tamsal formation, is north-

west of the village and railroad station, Tamsal. The rock is there quarried for lime, an extensive plant being in operation. This is taken as the type-locality of the zone, since Schmidt gives none, as well as the type of the formation. About twelve feet of strata are visible here, the basal two feet belonging to the Jörden beds and the upper ten feet to the Borealis banks.

The rock is a gray and yellowish gray *Pentamerus borealis* breccia. No two valves were seen together and little else can be seen. Clathrodictyon is the only other common fossil.

The rock at the Weissenfeld locality previously described (p. 317) is not so exclusively composed of *Pentamerus borealis*, and entire shells are not uncommon. At Helterma, on the island of Dago, the beds outcrop on the beach and, as at Weissenfeld, the rock is not so completely a mass of Pentamerus, although parts are fully as much so. *Syringophyllum organum*, *Clathrodictyon vesiculosum* and other corals are not uncommon here. This outcrop may represent the upper portion of the division. The Borealis banks are also shown by eight or nine feet in the Podrang quarry near Tamsal, and there the shells do not make such a great proportion of the beds.

From the localities cited it appears probable that only the lower portions of this zone have been seen, unless the exposures at Helterma lie above the base. Schmidt was inclined to believe that the Borealis banks lose their character as a unit upon the island of Dago, reaching this opinion from finding *P. borealis* in the Jörden beds at Kallasto. This is by no means certain, as this shell also occurs in the Jörden beds at Tamsal, and in some places it should be more abundant than elsewhere in this basal division, and perhaps this is the case at Kallasto. As a shell breccia, the division probably has only a local development.

The fauna of this division has never been carefully studied. It is probably not large, since the conditions of fossilization were not such as to lend themselves to the preservation of delicate forms. The omnipresent fossil is *Pentamerus borealis*. *Syringophyllum organum*, *Favosites gothlandicus*, *Clathrodictyon vesiculosum*, and small bryozoans occur more or less rarely.

(c) *Raiküll beds.* This division is the thickest of the three belonging to this formation, Schmidt stating that 100 feet may be present. It appears to be continuous with the Borealis banks, and receives its name from Raiküll, the estate of Count Keyserling. In general, the rock is a coralline limestone, in some places completely dolomitized, in others a mass of corals, and in still others well-bedded crystalline limestone. The division makes its appearance about twenty miles

west of Lake Peipus, reaches the coast south of Hapsal and forms a part of the south end of Dago. In the east it outcrops over an area about thirty miles wide from north to south, but south of Hapsal the belt of its outcrops is only a few miles wide.

The quarry of the type-locality is in a forest about three miles northwest of the Raiküll residence, and is reached by a road branching off from the main road a little to the west of the entrance to the estate (Plate **3**, fig. 2). About ten feet are exposed. The lower eight feet consist of well-bedded, probably dolomitic limestone with the beds varying in thickness from three to eight inches and these are extensively quarried for construction purposes. Very few fossils are present. The upper two feet consist of thin-bedded rough limestone in which are many corals, chiefly *Favosites gothlandicus*, *Halysites catenularia*, and *Clathrodictyon vesiculosum*.

Certain beds of this zone are much more extensively exposed near the village Lippa, situated about three miles south of Raiküll. The quarry covers an acre or two and appears to have been continuously operated for many years, but only about four feet of strata are exposed. The rock is a hard, white, crystalline limestone with which is interstratified a little softer, almost microcrystalline limestone of the same color. The former is dolomitic, and both are in beds from three to six inches thick. At the top are myriads of corals, many of which are silicified. They are not uniformly distributed through the rock, but are aggregated in patches and the species are the same as mentioned for the Raiküll locality and, in addition, many Heliolitidae are also present. A layer of the softer crystalline limestone is particularly characterized by numerous, fine, large specimens of *Leperditia keyserlingi* Schmidt.

A more extensive exposure of this division is near Weissenstein on the Müntenhof estate, where the beds exposed reach a thickness of twenty feet. The lowest fifteen feet consist of well-bedded bluish and yellowish crystalline dolomitic limestone in which only obscure fossils were seen and these were near the top. The beds are from four to six inches thick, and one about two feet below the top contains flattened mud pebbles with the horizontal diameters reaching an inch and the vertical diameters about a fourth as great. Overlying these strata are from five to six feet of cavernous yellow dolomite with gnarled structure and a general absence of bedding. This is probably an old coral reef and it still contains numerous poorly preserved specimens of Favosites and Clathrodictyon. Many of these are merely skeletons and after the exterior has been broken, crumble on being touched.

On the coast south of Hapsal, near the village Pasko, are extensive exposures of a white crystalline limestone. The outcrops are on the beach, and the rock appears to have been formed from an old coral reef. Well-preserved coral masses strew the beach and have contributed a great deal of material to the many stone walls of the adjoining lands. These are the most fossiliferous exposures of this division that were seen. The corals consist of Favosites, Heliolitidae, Halysites, Clathrodictyon, Syringophyllum, Acervularia and several species of horn corals.

Other localities where the Raiküll beds are exposed are Mexhoff, Piometz, Endama, Allenküll, Teknal, Wieso, Wödja, Tenja, and the island Kassar to the south of Dago.

Besides the corals mentioned as being present in the Raiküll beds, there are the trilobites *Encrinurus punctatus*, *Illaenus livonicus* Holm, *Phaeops elegans* Sars and Boeck, *Proetus planedorsatus;* the bryozoans *Vincularia megastoma* Eichwald and *V. nodulosa* Eichwald. Brachiopods appear to be quite rare. At Raiküll and Wahloküll Schmidt states the occurrence of the graptolite *Diplograptus estonus* Schmidt [1] and at the latter place *Deiphon forbesi* Barrande.

Addifer formation. This formation was designated by Schmidt the *Pentamerus estonus* beds by reason of the great numbers of that brachiopod which are commonly present. The section exposed in the quarry at Addifer, the estate of Herr E. von Wahl, is taken as the type.

The outcrops of the Addifer formation begin about twenty miles west of Lake Peipus near Pedja Brook and reach the sea south of Hapsal. It has not been identified on the islands, but may underlie the extreme southern end of Dago, and probably does underlie Soela Sound between the islands of Dago and Oesel. The thickness of the formation has never been accurately determined, but it appears that not more than fifty feet are present.

The formation is separated from that underlying, chiefly on the basis of the introduction of *Pentamerus estonus* Eichwald, *Atrypa reticularis* (Linné) and *Eospirifer radiatus* (Sowerby). So far as known, its stratigraphic relations to the Raiküll beds and St. Johannis formation are those of conformability.

The designation, *Pentamerus estonus* beds, does not carry the idea that the rocks are largely composed of the shells of one species, as is the case in the *P. borealis* beds. In this formation the pentamerids

[1] Mem. Acad. imp. sci. St. Petersb., ser. 7, **30**, no. 1, p. 44.

lie in colonies at various levels, in some places composing the whole of the rock and in others only a few or none being present.

The greater portion of the rock of the formation appears to be composed of a yellowish white, fine-grained limestone which is only partly crystalline; or a coarse-grained, quite crystalline, dolomitic limestone. At some levels or localities there is also a little shale. Schmidt (*Loc. cit.*, 1882, p. 526) states that in the east dolomites prevail, while in the west the lithology is one of coralline limestone. In a general way this conclusion appears justified. Also, in the eastern limits, either the upper beds of this formation, or the lower beds of the succeeding, consist of unfossiliferous sandstone which Schmidt at first considered Devonian; but he later learned that the sandstone is overlain by the fossiliferous beds of the St. Johannis formation which necessitated his referring the former to the Silurian.[1]

Addifer, the type-locality, is in the eastern area. The exposures are in an old quarry which has recently been reopened. About ten feet are shown of which the lower six feet are typical *Pentamerus estonus* limestone. The brachiopods are not uniformly distributed, but occur in patches and in these they are extremely abundant. Many are silicified, but others show no microscopic trace of silica. Flint nodules are very abundant and many are several inches long. The floor of the quarry is composed of a coarse-grained, quite crystalline, dolomitic limestone. How thick this is, was not learned. The upper four feet of the quarry section consist of a whitish yellow, fine-grained, partly crystalline limestone, which, except for a few poorly preserved corals, appears to be without fossils. It contains a few white flint nodules. Near one of the barns about the residence of this estate a ditch has recently been constructed, and in it the same sequence as in the quarry is shown.

East of the railroad station, Wochma, about fifteen miles from Addifer, are the old quarries of Koksfer, and Arrosaar. They are largely grassed over, but a few of the old dumps permit collecting. The rock appears to be a coarsely crystalline dolomitic limestone. Fossils seem to be rare, consisting chiefly of Halysites, Cyathophyllum, Favosites, and Zaphrentis. *Pentamerus estonus* was not seen. Many yellow or brownish yellow flint concretions are present. These strata are higher than those of Addifer.

At Pajus, a few miles east of Addifer is a small exposure of about five feet of soft yellow limestone containing no observed fossils, but a

[1] Schmidt. Loc. cit., 1881, p. 46.

considerable number of flint concretions occur. Another quarry at Pajus has an exposure of about eight feet of finely crystalline hard limestone in beds up to eight inches thickness. A few poorly preserved corals were the only fossils seen. These two exposures are near the base of the Addifer formation, and they may belong to the Raiküll beds.

At Nudi, about five miles south of Raiküll, and on lower ground, is an old abandoned quarry, once extensively worked. About four feet of horizontal strata are exposed of which the basal two feet consist of thin-bedded, gray crystalline limestone with thin shale partings, and the upper two feet of thin-bedded, poorly crystalline white limestone. Fossils are quite common throughout and in some layers they are very abundant. *Atrypa reticularis*, Pentamerus, like *P. oblongus* from the Clinton of New York, and *Eospirifer radiatus* are those most common. These strata probably are situated quite near the base of the formation.

The formation is excellently exposed at Kattentack near the village Turpel. About four feet of thin-bedded limestones are exposed in which corals are the chief fossils, these consisting of Favosites, Lyellia, Halysites, and Zaphrentis. Large *Pentamerus estonus* and *Orthis cf. calligramma* Dalman are also not uncommon.

Other localities where the strata of the formation can be seen are Kerro, Fennern, and Keskfer.

The fauna of the Addifer formation is evidently quite large, but has not been well studied or collected. Important species are: —

1. Alveolites labechi Milne Edwards.
2. Darwinia speciosa Dybowski.
3. Favosites gothlandicus.
4. hisingeri Milne Edwards and Haime.
5. Halysites catenularia.
6. distans Eichwald.
7. exilis Eichwald.
8. Syringopora bifurcata Lonsdale.
9. Vincularia megastoma.
10. nodulosa.
11. Atrypa reticularis.
12. Eospirifer radiatus.
13. Pentamerus estonus.
14. Schuchertella pecten (Linné).
15. Strophomena euglypha Dalman.
16. Orthoceras canaliculatum Sowerby.

17. Leperditia abbreviata Schmidt.
18. Calymene frontosa Lindström.
19. Encrinurus punctatus.
20. Goldius estonicus Schmidt.
21. cf. marklini Angelin.
22. Illaenus livonicus Holm.
23. proles.
24. Phacops elegans.
25. Proetus concinnus Dalman.

St. Johannis formation. By Schmidt this formation was designated the Lower Oesel zone, or stage I. It makes its first appearance on the mainland just west of the village of Fennern, where it overlies the Addifer formation and appears from beneath the Devonian. It forms the surface rock of the north end, and probably most of the central and southern parts of Moon, and all of the northeastern half of Oesel. The exposures of the mainland are negligible; but on the islands there are many and no difficulty need be experienced in obtaining a representative collection. Several of the best localities are the island of Schildau between Moon and the mainland, St. Johannis on the northeast corner of Oesel and Mustel or Panga Pank (cliff) on the northwest corner. It is the only Silurian formation of this region of which a nearly completely continuous section is shown.

The formation has a thickness of about 100 feet, consisting of a variation of dolomites and limestones interbedded with highly calcareous shales. As has been previously noted, perhaps there are beds of sandstone in the lower part of the formation in its eastern exposures. In the western areas many of the beds are markedly dolomitic, and some of the dolomitic beds carry hardly any fossils.

Nearly the entire formation is shown at Mustel Pank on the northwest coast of Oesel. At sea-level (Schmidt, 1858, p. 60) are beds of limestones which are chiefly composed of corals. These are succeeded by gray or blue calcareous shales rich in fossils. There are probably not more than ten feet of these. Above follow compact gray limestones with shale partings, and this zone traced horizontally appears to pass over into gray or yellow, often porous, crystalline dolomites. Somewhere in this Mustel Pank section is said to be the horizon of the occurrence of *Schidosteus mustelensis* Pander.

One of the most westerly of the good fossil localities, and one of the few of the mainland was Kerkau which Schmidt[1] considered to lie at

[1] Schmidt. Loc. cit., 1858, p. 61.

about the same horizon of the marl beds at St. Johannis. At that place the rock is said to be quite dolomitic. The exposure is no longer in existence. Fossils which have been collected there are: —

1. Eospirifer radiatus.
2. Leptaena rhomboidalis.
3. Meristina tumida (Dalman).
4. Platystrophia biforata lynx.
5. Spirifer crispus Dalman.
6. Orthoceras canaliculatum.
7. Calymene tuberculata Brunn.
8. Encrinurus punctatus.
9. Oncholichas cf. gothlandicus Angelin.
10. ornatus Angelin.
11. Proetus concinnus osiliensis Schmidt.

At Leal, on the western end of the mainland, the once extensive quarries are now to a considerable extent overgrown. The rock is a fine-grained dolomite which becomes yellowish white on exposure. Originally there may have been twenty feet exposed, but at present not more than one third of this is shown. Few fossils appear to be present.

At Kuiwast on the eastern side of the Island of Moon, a brownish gray to yellowish white, fine-grained crystalline dolomite outcrops on the beach. At most levels it has a gnarled structure and appears to be largely composed of coralline material, although the fossils have been completely destroyed. In a few places the bedding is regular.

A similar rock, but with bedding in some places well defined, outcrops at many localities on Moon. At the base of Igo Pank and Pussininna Pank occur soft, bluish gray and yellow, not well or finely crystallized dolomites with well-defined bedding. The overlying rocks are cavernous dolomites which, being more resistant to wave-erosion than the softer underlying strata, overhang the latter in many places, producing a wild and picturesque coast. Fossils are quite rare in the rocks at the top of the cliffs, but in the softer beds beneath they are more common. The former beds are probably the same as those of Kuiwast, and they appear to compose most of the surface strata of the northern interior of Moon.

Fossils from the basal beds of the two Panks mentioned are: —

1. Hindia fibrosa Roemer.
2. Halysites catenularia.

3. Ptychophyllum patellatum Schlotheim.
4. Atrypa reticularis.
5. Camarotoechia bidentata (Hisinger).
6. Dalmanella elegantula.
7. Dinorthis rustica osilensis (Schrenck).
8. Leptaena rhomboidalis.
9. Spirifer crispus.
10. Strophomena euglypha.
11. Wilsonia wilsoni (Sowerby).
12. Omphalotrochus discors (Sowerby).
13. Orthoceras canaliculatum.
14. Encrinurus punctatus.

At Kaggowasar on Moon have been collected *Acidaspis marklini* Angelin, *Bumastus barriensis* Murchison, and *Proetus* cf. *P. verrucosus* Lindström.

At Orrasaar on the east coast of Oesel, about 150 yards north of the post station, occur many blocks of a marly semicrystalline, yellowish gray dolomitic limestone which contains numerous small fossils. The blocks were probably pushed up by the ice from beneath the sound between Moon and Oesel, and appear to have been derived from about the same horizon as the rock at the base of Igo Pank. From these blocks have been obtained: —

1. Lyellia tubulata Lonsdale.
2. Favosites gothlandicus.
3. Ptychophyllum patellatum.
4. Wilsonia wilsoni.
5. Omphalotrochus funatus.
6. sculptis.
7. Pleurotomaria alata Wahlenberg.
8. Phragmoceras pyriforme (Sowerby).
9. Orthoceras canaliculatum.
10. Beyrichia klodeni McCoy.
11. Calymene tuberculata.
12. Encrinurus punctatus.
13. Proetus concinnus osiliensis.

On the island of Schildau between Moon and the mainland the same sequence appears to obtain as on Moon, but somewhere in the lower beds there is a level containing many fine fossils similar to those of the locality at St. Johannis described in the next paragraph. I did

not visit this island, but saw a collection from these rocks in the cabinet of Herr E. von Wahl.

The best locality for excellent fossils of this formation is without doubt the one which is taken as the type. This is near St. Johannis church on the northeast corner of Oesel. About a mile southeast of the church the rock is a compact, crystalline dolomitic limestone with hardly any fossils. Beneath this lies a somewhat softer dolomitic limestone in which are many large corals, belonging to Clathrodictyon, Favosites, Halysites, and Syringopora. These beds probably correspond to some part of the upper beds of Mustel Pank and Moon. Underneath are the strata of St. Johannis church, consisting of white, porous, marl-like limestones. Directly at St. Johannis the rock is not seen in place, but blocks are not uncommon on the shore, and about a mile northwest it forms a cliff. It yields readily to the action of water and, since the fossils are more resistant than the inclosing rock, they have not been destroyed; but concentrated on the beach. Where exposed northwestward there is a cliff about ten feet high with the marly limestones quite thick-bedded and bedding not well defined. Fossils are not so common as at St. Johannis, as here there has been no concentration.

There is no place in all the Russian Baltic where fossils are so abundant and so beautifully preserved. Species which have been collected at St. Johannis are: —

1. Hindia fibrosa.
2. Campophyllum irregulare Dybowski.
3. Cystiphyllum cylindricum Lonsdale.
4. Favosites gothlandicus.
5. Halysites escharoides.
6. distans.
7. exilis.
8. Ptychophyllum patellatum.
9. Vincularia nodulosa.
10. Atrypa reticularis.
11. Camarotoechia bidentata.
12. Cyrtia exporrecta (Wahlenberg).
13. Dalmanella elegantula.
14. Dinorthis rustica osilensis.
15. Eospirifer radiatus.
16. Meristina tumida.
17. Leptaena rhomboidalis.

18. Rhipidomella hybrida (Sowerby).
19. Plectambonites transversalis (Dalman).
20. Spirifer crispus.
21. Schuchertella pecten.
22. Strophomena euglypha.
23. Wilsonia wilsoni.
24. Omphalotrochus funatus.
25. sculptis.
26. Cornulites vagans Schrenck.
27. Tentaculites ornatus Sowerby.
28. Orthoceras annulatum Sowerby.
29. canaliculatum.
30. Beyrichia klodeni.
31. Acidaspis marklini Angelin.
32. Bumastus barriensis.
33. Calymene tuberculata.
34. Cyphaspis elegantula Angelin.
35. Encrinurus punctatus.
36. Proetus concinnus osiliensis.
37. Aulacodus obliquus Eichwald.

Numerous crinoid stems and at least four additional species of Bryozoa are also present.

Strata of this same horizon are said to make their appearance on the small island of Keinast between Oesel and Moon, and Schmidt reports *Palaeocyclus porpita* (Linné) and *Caryocrinus ornatus* Hall to have been collected there. It is extremely probable, however, that the latter identification is incorrect. Farther westward on Oesel at Surika Pank and Hundwa Pank, the lithology of the formation becomes less dolomitic. As a consequence, fossils are better preserved and, among others, Schmidt notes the occurrence of *Thecia swindernana* Goldfuss, *Eridophyllum rugosum* Milne Edwards and Haime, *Camarotoechia borealis* (Schlotheim), *Rhynchotreta cuneata* (Dalman), and *Leperditia baltica* Hisinger.

Oesel formation. This represents the Upper Oesel group of Schmidt and with it the Silurian of Esthonia ends. The surface exposures of the formation appear to be confined to the southwestern side of Oesel, but there is a possibility that it finds representation among the higher rocks of Moon. It appears to be a direct continuation of the St. Johannis formation and, since there is no appreciable variation of dip, the stratigraphic relations are considered conformable. Probably

between fifty and seventy-five feet are represented, consisting of a complex of dolomites, limestones, and shales. In the interior of Oesel to the northwest of Arensburg, the rocks are chiefly yellow crystalline limestones, and dolomites and a similar lithology obtains on the northern end of its outcrops on the western shores, to as far south as Sarepa.

On the south coast to the east of Arensburg, the strata consist of heavy-bedded limestones and shales, and the lithic facies on the Sworbe to the southwest of the city is very like that of the southern coast, although there is not so much of the massive limestone, and calcareous shales appear to have a larger representation. These strata are younger than those described in the preceding paragraph.

Since there are two lithic units in this division it may ultimately prove necessary to give formational rank to each. I have hesitated to do this because of the apparent impossibility of determining a basis, or locating a plane of division. The latter, however, is a common and almost universal difficulty throughout the Esthonian region. None has been determined between the St. Johannis and this formation, but the latter is assumed to begin with the appearance of *Whitfieldella didyma* (Dalman), *W. prunum* (Hisinger) and the eurypterids. For convenience, however, the two divisions of this formation will be described as the Sagaristi and Kaugatoma zones, after the localities which are considered typical of the lower and upper divisions.

(a) *Sagaristi zone.* The most northern and lowest exposures of the interior are those of Sagaristi, Uddafer, and Ladjal. At Sagaristi not more than four feet of strata are exposed, consisting of interstratifications of coarsely crystalline gray and yellow limestones (beds one to three inches thick), white to yellowish white poorly or finely crystalline dolomitic limestones and thin calcareous shales. The dolomitic limestones appear to be much used for flags and building stones. Fossils are extremely common in patches, but the fauna is dominated by the abundance of *Whitfieldella didyma* and *Rhipidomella hybrida.* The former in some places occurs by hundreds. The same strata with a similar lithology are well exposed in quarries extending from Uddafer to Ladjal, but the thickness shown is considerably greater. The following fossils have been collected from these localities: —

1. Clathrodictyon vesiculosum.
2. Favosites gothlandicus.
3. Laceripora cribrosa Eichwald.

4. Syringopora reticulata Hisinger.
5. Whitfieldella didyma.
6. prunum.
7. Rhipidomella hybrida.
8. Murchisonia cingulata Hisinger.
9. Platyschisma helicites (Sowerby).
10. Pleurotomaria undata Sowerby.
11. Holopella obsoleta Sowerby.
12. Ilionia prisca (Hisinger).
13. Pterinea retroflexa Wahlenberg.
14. Orthoceras imbricatum Wahlenberg.
15. Leperditia baltica.
16. Encrinurus? obtusus Angelin.
17. Eurypterus fischeri Eichwaldi.

The exposures northwest of Arensburg and on the west coast are rarely extensive, consisting of small quarries in the interior and a few low cliffs on the coast.

Padel, about nine miles from Arensburg and on the road to Rotziküll, has an exposure of fully four feet of very finely crystalline limestone which in fresh exposures is probably thick-bedded, but under the action of sun and frost the rock separates into thin slabs. The fauna is the same as that at Sagaristi, and *Whitfieldella didyma* is the most common fossil. About a mile west of Padel is the Koggul quarry. The elevation is in the neighborhood of ten feet higher and the beds may be a little higher stratigraphically, but there is no certainty regarding this point. About ten feet of thick-bedded, chocolate colored limestone are exposed. Fossils are not abundant; but large omphalotrochoid gastropods and small *Whitfieldella didyma* are not uncommon. Other fossils from here are *Crotallocrinus rugosus* Miller, *Aviculopecten danbyi* (McCoy), *Goniophora cymbaeformis* Sowerby, *Megalomus gothlandicus* Lindström, and *Encrinurus punctatus*. A form closely related to *Eospirifer radiatus* also occurs at this locality. Another small quarry at Limadau exposes about two feet of very hard compact limestone containing hardly any fossils.

Rotziküll is the noted eurypterid locality, made famous through the labors of Schmidt, Holm, and others, and which has long been the European Mecca for students of this group of organisms. The eurypterid layer is well exposed in a small quarry on the shore to the south of the village and the base of the quarry is from six to eight feet above sea-level. At the base are eighteen inches of white fine-grained

dolomite in which the Eurypterus fauna is magnificently preserved. Eurypterids from here are *Bunodes lunula* Eichwald, *B. rugosus* Nieszkowski, *B. schrencki* Nieszkowski, *Eurypterus fischeri* Eichwald, *Pseudoniscus aculeatus* Nieszkowski, and *Pterygotus* sp. An Orthoceras, *O. tenuis* Wahlenberg, is quite common in the eurypterid layer and there are also two cephalaspidian fishes, *Thyestes verrucosus* Eichwald and *Tremataspis schrencki* Schmidt. This layer is overlain by about eighteen inches of mottled yellow and gray, nearly unfossiliferous limestone from which have been collected a few fish scales, *Leperditia angelina* Schmidt and *Platyschisma helicites.*

What is probably the same eurypterid horizon is exposed on the seashore at Attel, about six or seven miles southwest. The rock nearest the water-level consists of two feet of gray to white dolomitic limestone in one to four inch beds. Some of the beds are crowded with *Leperditia angelina* while others have many eurypterids. Masses of Clathrodictyon up to two feet in diameter are associated in the same beds with the eurypterids and toward the top is a thin layer which has the appearance of being a conglomerate, but it may be that the "pebbles" are of organic origin. The upper portion of the beach is covered with debris, and it is probable that from five to six feet of strata are concealed. At the top of the beach is a low cliff in which about four feet of thick-bedded gray limestone are shown. Below the dolomitic beds at the water's edge there appear to be beds of coralline limestone with many stromatoporoids.

Between Rotziküll and Attel are the exposures of Lello Brook. These are a little above the eurypterid beds and show about six feet of thin-bedded limestone, containing many *Platyschisma helicites*, and in some layers numerous *Leperditia angelina.* Many fish remains, chiefly scales, have also been collected. Species of fish from this place are: —

1. Coccopeltus asmussi Pander.
2. Coelolepis carinatus Pander.
3. goebeli Pander
4. laevis Pander.
5. schmidti Pander.
6. Coscinodus agassizi Pander.
7. Ctenognathus murchisoni Pander.
8. Cyphomalepis egertoni Pander.
9. Dasylepis keyserlingi Pander.
10. Dictyolepis bronni Pander.

11. Loptholepis schmidti Pander.
12. Melittomelepis elegans Pander.
13. Otontodus rootsiküllensis Pander.
14. Prionacanthus brandti Pander.
15. dubius Pander.
16. Rytidolepis quenstedti Pander.
17. Stigmolepis oweni Pander.
18. Strosipherus indentatus Pander.
19. laevis Pander.
20. serratus Pander.
21. Trachylepis formosus Pander.

South of Attel are small exposures at Karral and Sarepa, but not more than four feet of thick-bedded gray limestone are shown at either place. The horizon is perhaps a little higher than the highest beds of Attel, but may be the same. At Sarepa *Cyphaspis elegantula*, *Illaenus sulcatus* Lindstrom and other fossils have been collected. At Hoheneichen, a few miles inland from Sarepa, a few feet of thick-bedded limestone are exposed in which *Labechia conferta* Lonsdale occurs in great abundance, and from which *Phlebolepis elegans* Pander and *Schidiosteus mustelensis* Pander have also been collected.

(b) *Kaugatoma zone.* This zone is excellently exposed along the southern coast to the east of Arensberg and on the Sworbe, the south-western peninsular extension of Oesel. It is more fossiliferous than the Sagaristi zone.

On the southern shore there are quite a number of important exposures of which the more extensive are those of Moritz, Kasti, Nessoma, and Lode, the last being west of Arensberg.

The Moritz locality is on the road to Nessoma and is about four miles east of Arensberg. No rocks in place are now visible, the quarry having been abandoned, and it is at present largely overgrown. The strata appear to have been alternations of thin shales and coarsely crystalline, black and gray limestones. Corals and crinoid stems excepted, good fossils do not appear to have been common. Corals are abundant, chiefly Clathrodictyon and *Acervularia luxurians* Eichwald. The crinoid stems belong to Crotallocrinus and the most common brachiopod is *Whitfieldella prunum.* Some of the limestones have the Caudigalli effect on their upper surfaces.

Near Kasti two small quarries were examined, each about a mile westward from the dwelling of the Kasti estate. One is on the shore and exposes about three feet of gray crystalline limestone (beds four

to six inches thick) with thin shale partings. Few fossils appear to be present. The second quarry is situated on the side of a hill at an elevation of about fifteen feet above the shore quarry. The rocks consist of gray crystalline limestones interstratified with gray calcareous shales. Only about three feet are shown. A single limestone bed near the base has the Caudigalli effect on its upper surface, and this same surface has many beautifully preserved *Schuchertella pecten* and *Rhipidomella hybrida,* of which a great many are single valves showing excellent interiors. Numerous fragments of *Calymene spectabilis* Angelin are also present. The other limestone beds contain many corals and crinoid stems like those of Moritz.

About a mile farther eastward, at about the same elevation and presumably about the same horizon, is a large quarry which has recently been reopened. About five feet of strata are exposed, consisting of very fossiliferous gray crystalline limestones, and thin calcareous gray shales. Some of the shale bands are filled with small Spirifers and Rhynchonellas, while the limestone beds are thickly crowded with large Crotallocrinus stems. The old dump heaps afford splendid collecting. Common fossils of the beds of this quarry are: —

1. Clathrodictyon sp.
2. Favosites gothlandicus.
3. Spongophyllum contortiseptum Dybowski.
4. Hallopora elegantula.
5. Monticulipora fletcheri Milne Edwards and Haime.
6. Ptilodictya lanceolata Hisinger.
7. flexa Hisinger.
8. Chonetes striatellus Dalman.
9. Orthis canaliculata Lindström.
10. Homeospira salteri (Davidson).
11. Spirifer elevatus Hisinger.
12. Tentaculites curvatus Boll.
13. inaequalis Eichwald.
14. Calymene spectabilis Angelin.

The Nessoma quarries are just above sea-level, and cover several acres. The strata consist of thick-bedded black to dark gray mottled limestone with thin shale partings. Not more than five feet are exposed. Some of the beds of limestone are fully a foot thick, and afford excellent dimensional stone. The quarries are being actively developed, and at the time of my visit about a score of men were employed, the stone being shipped to Riga, Pernau, Hapsal, Arensberg,

and perhaps other towns. Fossils are quite common, but generally not well preserved. Those most common are *Acervularia luxurians*, Clathrodictyon, large stems of Crotallocrinus, *Whitfieldella prunum*, *Ctenognathus murchisoni* Pander, and *Gomphodus sandelensis* Pander. The horizon is practically identical with that of Moritz.

The Lode locality is about two miles west of Arensberg, and the present exposures are in an old well of which the top is not more than ten feet above sea-level. About six feet of interstratified gray and blue limestones and shales are exposed, which appear to belong to nearly the same horizon as that of Kasti or Moritz. The fossils were collected on the dumps, those most common being *Crotallocrinus rugosus* Miller, *Monticulipora fletcheri*, *Rhipidomella hybrida*, *Homeospira salteri*, *Spirifer elevatus*, *Whitfieldella prunum*, *Calymene spectabilis*, and *Proetus conspersus* Angelin.

About the most fossiliferous locality of the Kasti zone is that of Kaugatoma Pank on the Sworbe, where strata are exposed which excellently typify the lithology of the upper division of the Oesel formation. The height of the cliff at Kaugatoma Pank hardly exceeds twelve feet, but the exposures are increased by several feet which are shown on the beach. At the water's edge are three to four feet of thin limestones and calcareous shales, the latter being filled with extremely fine fossils. The upper portion of the beach is covered and about four feet of strata are concealed. The lower five feet of the cliff consist of thin limestones and shales like those below, and contain essentially the same fossils. At the top of the cliff are six or seven feet of heavy-bedded limestone which is quite similar to that of Nessoma and elsewhere on the southern coast. The species whose names follow have been collected.

1. Acervularia luxurians.
2. Alveolites repens Fought.
3. Clathrodictyon vesiculosum.
4. Cyathophyllum articulatum Hisinger.
5. Favosites cristatus Blum.
6. forbesi Milne Edwards and Haime.
7. hisingeri Milne Edwards and Haime.
8. Omphyma subturbinata d'Orbigny.
9. Syringopora reticulata.
10. Crotallocrinus rugosus.
11. Fenestella subantiqua d'Orbigny.
12. Monticulipora fletcheri.

13. Ptilodictya lanceolata.
14. Camarotoechia nucula (Sowerby).
15. Chonetes striatellus.
16. Leptaena rhomboidalis.
17. Retzia salteri.
18. Rhynchonella diodonta Dalman.
19. Spirifer elevatus.
20. schmidti Lindstrom.
21. Strophomena filosa Sowerby.
22. Spirorbis imbricatus.
23. Autodetes calyptratus (Schrenck).
24. Euomphalus? catenulatus Wahlenberg.
25. cornuarietis Wahlenberg.
26. Holopella obsoleta Sowerby.
27. Pterinea reticulata Hisinger.
28. retroflexa Wahlenberg.
29. Orthoceras bullatum Sowerby.
30. Calymene intermedia Lindström.
31. spectabilis.
32. Proetus conspersus.

Farther southwest on the same coast is the Ohhesaare Pank in which strata of about ten feet in thickness are exposed, consisting of interstratifications of gray and red sandy limestones and calcareous shales of various shades of brown, the latter dominating in the middle of the section. The sandy limestones contain many small remains of fishes, while the shales carry numerous pelecypods of which *Grammysia cingulata* Hisinger is probably the most abundant. The invertebrate fauna is quite similar to that of Kaugatoma Pank, but the presence of fish remains and the absence of crinoids are marked features of difference. These differences are probably to be referred to differences in the ecologic facies during the times of sedimentation. The complete fauna from Ohhesaare Pank is as follows: —

1. Favosites cristatus.
2. forbesi.
3. Trachypora porosa Dybowski.
4. Dianulites elegantulus Dybowski.
5. Hallopora elegantula.
6. maculata (Dybowski).
7. Ptilodictya lanceolata.
8. Chonetes striatellus.

9. Dalmanella elegantula.
10. Retzia salteri.
11. Spirifer elevatus.
12. Cardiola interrupta Broderip.
13. Modiolopsis complanata Sowerby.
14. Pterinea reticulata.
15. retroflexa.
16. Autodetes calyptratus.
17. Holopella obsoleta.
18. Tentaculites annulatus Schlotheim.
19. inaequalis.
20. Orthoceras bullatum.
21. tracheale Sowerby.
22. Beyrichia wilkensiana Jones.
23. Leperditia phaseolus Hisinger.
24. Calymene intermedia.
25. spectabilis.
26. Phacopidella downingiae (Murchison).
27. Gomphodus sandelensis.
28. Lophosteus superbus Pander.
29. Monopleurodus ohhesaarensis Pander.
30. Nostolepis striatus Pander.
31. Onchus curvatus Pander.
32. murchisoni Agassiz.
33. tricarinatus Pander.
34. Oniscolepis crenulatus Pander.
35. dentatus Pander.
36. magnus Pander.
37. serratus Pander.
38. Pachylepis costatus Pander.
39. glaber Pander.
40. Pterichthys harderi Pander.
41. Rabdacanthus truncatus Pander.
42. Tolypelepis undulatus Pander.

It is possible that strata of the Oesel formation occur on the island of Moon. Schmidt states that material which was brought to him by a peasant, which was said to have been obtained on Moon from an excavation for a spring, was of the same lithic aspect as the rock of the Kaugatoma zone of the Oesel formation, and contained *Whitfieldella prunum*, *Spirifer elevatus*, and *Homeospira salteri*. The gen-

eral unreliability of unscientific statements relating to locality, however, gives to the above data no other value than that it should be kept in mind in future explorations on Moon.[1]

Time Equivalents of the Silurian Formations.

Until the fossils have been carefully studied all correlations must be merely tentative and based on published lists and field-identifications. While the conclusions reached may contain something of error, it does not appear likely that the probability of error is very great.

The Silurian faunas of Esthonia do not appear to have nearly so much in common with the North American faunas of the same time, as existed between those of the highest Ordovician beds of the two countries. The common Russian Silurian corals are largely the same as those of North America, but that has little meaning as all of them are long ranging. The gastropods and pelecypods are decidedly different, the Bryozoa have been subjected to little comparative study, so that reliance must chiefly be placed on the trilobites and brachiopods. As with the Ordovician, comparison will be made with the Anticosti section.

The Addifer formation affords the best points of contact for therein *Atrypa reticularis*, *Eospirifer radiatus*, *Pentamerus estonus*, and *Syringopora bifurcata* make their first appearance. In the Anticosti section, these species or their equivalents, appear for the first time in the very topmost portion of the Gun River formation and are typical of the Jupiter River. Using first appearances as a point of departure, leads to the correlation of the Addifer formation with possibly the uppermost zone of the Gun River and certainly the lower and middle portions of the Jupiter River, that is, Clinton. One, however, notes the conspicuous absence of such common Clinton forms as *Coelospira hemispherica*, the Stricklandinias, and *Bilobites bilobus*, as well as others not so commonly occurring.

The Tamsal formation would then be represented by the middle and perhaps the lower portions of the Gun River formation; but, corals excepted, there is little specific faunal evidence supporting the correlation. The general aspect of the fauna, however, is not so old as that of the Becsie River faunas. A conclusion can be reached if the faunas of a region intermediate in position be selected for common comparison.

[1] Schmidt. Mem. Acad. imp. sci. St. Petersb., 1881, ser. 7, **30**, no. 1, p. 49.

The most diagnostic fossil in the Tamsal formation is *Pentamerus borealis*. In the Kristiana region, this is confined to the upper portion of Kiaer's zone 6c and to 7a, that is, to the uppermost zone of the Norwegian Lower Llandovery and the lowest zone of the Upper Llandovery, where it is associated in the latter zone with *Bilobites bilobus*, and in the former with *Plectambonites quinquecostata* McCoy (probably a different species since McCoy's form came from the Ordovician), *Coelospira hemispherica*, *Stricklandinia lens* Sowerby, and *Camarotoechia decemplicata* (Sowerby); all of which in the same or closely identical species make their first appearance in the uppermost zone of the Gun River formation, and this fact points to the probability that this zone, and probably some parts of the preceding zones, represent the Tamsal formation in the Anticosti section. If this view be correct, it follows that the equivalent of the Becsie River formation is not present in the Russian Silurian of the Baltic, and hence there is a considerable time break between the Borkholm and Jörden beds. It is worthy of note that the faunal break at this point is far greater than that between the Lyckholm and Wesenberg.

From one locality a small collection was made which in the field reminded me of the Cataract fauna, but until this collection has been studied and compared it is thought best to place no emphasis upon it. At any rate, it would not depreciate the correlation just made.

The St. Johannis formation is almost certainly the equivalent of the Wenlock of Scandinavia, England, and west Europe generally, and the Rochester and Niagara of North America. With the Wenlock of Norway, Kiaer's zones 8a to 8d, the formation has at least twenty-eight species in common, of which the more diagnostic are *Paleocyclus porpita*, *Thecia swindernana*, *Camarotoechia borealis*, *Cyrtia exporrecta*, *Dalmanella elegantula*, *Dinorthis rustica*, *Eospirifer radiatus*, *Meristina tumida*, *Rhipidomella hybrida*, *Rhynchotreta cuneata*, *Spirifer crispus*, *Wilsonia wilsoni*, *Omphalotrochus discors*, *Calymene tuberculata*, *Encrinurus punctatus*, and *Bumastus barriensis*. Correlation of the St. Johannis formation is therefore made with stage 8 (Wenlock) of the Norwegian sections. Since many of the fossils to which reference has been made in this paragraph also occur in the lower zones of Kiaer's stage 9 (Lower Ludlow) it is possible that the upper portion of the St. Johannis formation may find an equivalence in the lower portion of stage 9.

With the English Wenlock or Salopian series, the St. Johannis formation has nearly the same species in common as it has with the Norwegian section as well as some additional species and the correla-

tion is hence made with greater confidence. It is also possible that the upper beds of the St. Johannis formation have an equivalence with the Lower Ludlow of England.

As is to be expected, the case is not so sharply clear for the American sections; but no less than twenty species occur in the American Niagaran [1] or are represented by forms closely related. These are: —

1. Hindia fibrosa.
2. Cystiphyllum cylindricum.
3. Favosites gothlandicus.
4. hisingeri.
5. Halysites catenularia.
6. Paleocyclus porpita.
7. Atrypa reticularis.
8. Cyrtia exporrecta.
9. Dalmanella elegantula.
10. Eospirifer radiatus.
11. Leptaena rhomboidalis.
12. Meristina tumida.
13. Plectambonites transversalis.
14. Rhipidomella hybrida.
15. Rhynchotreta cuneata.
16. Schuchertella pecten.
17. Spirifer crispus.
18. Wilsonia wilsoni.
19. Calymene tuberculata.
20. Encrinurus punctatus.

There is little doubt that the above list will be lengthened when the St. Johannis fauna has been comparatively studied. Heliolitidae are present which are quite similar to the American species and such is the case with other forms of other groups. Since the fauna has by no means been carefully studied, only a few over fifty species having been recognized, this makes over thirty per cent of the fauna which has been recognized in the American Niagaran. It is also possible that the St. Johannis formation extends a little higher than the highest beds of the Niagaran.

In the Anticosti section the formation may find representation in the upper portion of the Jupiter River formation and almost certainly in the Chicotte, but the Anticosti series does not extend high enough to completely represent the Russian formation.

[1] Niagaran as here used excludes the Clinton.

The Kaugatoma formation is of Ludlow age, and has many faunal elements in common with rocks of that division in both Scandinavia and Great Britain, but with the Norwegian section the common species are not so many as desirable. Species of high diagnostic value which also occur in the Kristiana region of Norway in strata of Ludlow age (Kiaer's stage 9) are *Camarotoechia nucula*, *C. borealis*, *Chonetes striatellus*, *Retzia salteri*, *Spirifer elevatus*, *Grammysia cingulata*, *Megalomus gothlandicus*, and *Cardiola interrupta* (occurs in the strata of the preceding stage 8).

In the English Ludlow the same (*Megalomus gothlandicus* excepted) and other additional species occur, among the latter being *Aviculopecten danbyi*, *Cardiola interrupta*, *Orthonota cymbaeformis*, *Orthoceras bullatum*, *Crotallocrinus rugosus*, and also numerous eurypterids, some of which are closely related to those of the Oesel formation. While the identifications of some of the species named above are perhaps erroneous, enough are certain to assure synchroneity.

With the North American section the Oesel formation has few species in common and these are of almost universal distribution and of long range. The fauna of the Eurypterus beds, however, affords a most important point of faunistic contact. Schmidt first identified the common eurypterid (*E. fisheri*) as *E. remipes* De Kay and later both he and Holm agreed that it is little more than a geographic variety of the latter.[1] *E. remipes* is the common form of the Bertie Waterlime of the Salina group of New York and in addition to these two forms, there are others which are closely related. If then, the Sagaristi zone and the Bertie Waterlime be considered synchronous, it follows that the Kaugatoma zone finds an equivalence in the Cobleskill, Rondout Waterlime, and Manlius limestones.[2]

[1] Schmidt. Bull. Geol. soc. Amer., 1892, **3**, p. 59.

[2] No correlation has been made with the Gotland section for the reason that the data are not well enough in hand to warrant the attempt.

Part 3.—An Interpretation of the Silurian Section of Gotland.

INTRODUCTION.

The writer's hope of discovering new facts which might illuminate some of the intricate problems of Gotland's stratigraphy, and of being able to place before American students a detailed section of the strata, is his excuse for delving into this much studied field. The present discussion, which is intended to be preliminary to a more extensive treatment of the subject, attempts an interpretation of the lithic and faunal peculiarities of the stratigraphy. In the first part is given a description of some of the more important features which bear on the problem. This is followed by an interpretation of these features. Lastly, the various conclusions which have been reached are summarized.

In this study of the section, I was greatly assisted by Dr. Henry Munthe of the Swedish Geological Survey, a courtesy which is deeply appreciated.

Lithic and Faunal Characteristics of the Gotland Strata.

The Silurian rocks of Gotland have long been famous because of the abundance and excellent preservation of their fossils, and many of the great leaders of European geology have gone to the island as pilgrims to a shrine. The sequence of strata and the faunas have furnished the theme of numerous papers, and few of the masters of geology of northern Europe have refrained from in some way referring to the geology of this "Cross Roads of the Baltic." In spite, however, of the fact that numerous students have studied the various sections, there still is much that is uncertain and obscure. This arises from the absence of extensive exposures in the interior of the island, the decided horizontal variation of the sediments and their enclosed faunas, the numerous undulations of the strata, and the extensive discontinuities in the shore sections.

Without entering into a detailed discussion of the different views which have been held, attention will merely be called to the two divergent lines about which they may be grouped. Murchison (1847) considered that the strata dipped from northwest to southeast, that the beds of North Gotland are the oldest and underlie those of southern and central Gotland. In this view, he was later stoutly supported

by Dr. Friedrich Schmidt. The other view appears to have been first broached by Hisinger. According to him, the strata of Gotland are essentially horizontal with only a slight dip to the east, so that the same beds are found over many parts of the island. This view received strong support from Helmerson, F. Roemer, Angelin, Bather, Stolley, Wiman, Dames, and Lindström.

Among the latest published studies of the stratigraphy of Gotland are those from the pens of Drs. Henry Munthe and Herman Hedström, the former having studied the southern and the latter the northern half of the island. With some modification, Munthe appears to be in general agreement with the second view, while Hedström appears to adopt the views of Murchison and Schmidt with, however, considerable changes.

In general, the strata of Gotland have been said to fall into two lithic divisions; a lower, consisting of calcareous shales, thin limestones, oölite, and sandstones, and an upper, consisting of coralline and crinoidal limestones with subordinate shales. This grouping has been previously noted by Holm, Munthe, and others. It has generally been considered that the boundary between the two divisions is fairly sharp, but it is by no means certain that such is the case, since much which has been considered evidence of sharp division is capable of a different interpretation.

The detailed work of Munthe over the southern part of Gotland has given the classification which follows. The divisions are named from the summit downward.

1a Ascoceras limestone.
1b Youngest crystalline limestone.
2 Ilionia or Spongiostroma limestone.
3 Upper Sphaerocodium bed and oölite.
4 Sandstone with clay.
5 Lower Sphaerocodium bed.
6 Dayia flags.
7 Marl shale with lenses and bands of limestone.[1]

For northern Gotland Hedström has offered the following subdivisions, named in order from the highest to the lowest.

VII. Nonstratified reef limestones or stratified crinoidal and coralline limestones.
VI. Leperditia shales.
V. Oölitic limestones.

[1] Munthe. Guide book 11th. internat. geol. congr., 1910, no. 19. p. 49–50.

IVb. Ostracodan limestone, or marl shales and crinoidal limestone.
IVa. Bottom stratum with Stromatoporan limestone and Spongiostroma.
III. Upper cliff level of varying composition in different localities.
II. Lower cliff level.
I. Stricklandinia marl.[1]

Below the lowest visible strata of the northern end of the island are others which have been revealed by boulders on the shore near Visby. These consist of red shales containing the coral Arachnophyllum, on account of which they have been called the Arachnophyllum shales.

Each of the above classifications is subject to the same criticism, in that divisions have been named after fossils which by no means always occur, or after some lithic characteristic which is only locally present.

Attitude of the strata. This is the bone of contention over which opinion has clashed. In many places there appears to be a definite dip southeastward, but in an extremely great number of other places it can as definitely be determined that a pronounced dip in the opposite direction obtains. Since, however, the lowest visible division, or zone, is exposed only at the northern end of the western shore, near Visby, it appears reasonable to assume that there is a general gentle southeastward dip, from which, however, there are many reversals of inclination. The island of Storo Karlso excellently illustrates the directional variations of inclination. On the western side of the island the Marl shales are beautifully exposed to the south and north of the point on which the light-house stands and the beds dip into the sea. On the eastern side there are no exposures of the Marl shales, but overlying beds are extensively exposed and dip eastward into the sea, while on the coast of the main island directly opposite (Gotland), the Marl shales again appear with southeastward inclination (Plate **4**). At the Lau Canal the beds dip northwest at an angle of about fifteen degrees. These facts bear but one interpretation, *i. e.*, very little reliance can be placed on local inclinations in reaching conclusions relating to the general attitude, and from inclinations alone one can reach any conclusion desired, merely by selecting the proper place to reach the conclusion.

Variation of sediments and faunas. There is nothing more striking in the Gotland section than the horizontal variation of the sediments and their contained faunas. These variations are to be seen in many

[1] Hedström. Guide book 11th. internat. geol. congr., 1910, no. 20, p. 8.

localities of which only a few will be considered. One of the best exposures of the beds immediately above and below the Dayia flags is that of Lau Canal. This section has been described in detail by Munthe [1] and I merely wish to call attention to a few of the lithic and faunal variations. At the northwestern end of the canal the lithology is that of grayish blue laminated shales in which fossils — *Atrypa reticularis* excepted — are not common. Proceeding southeastward, a rising dip leads to a reef-like mass of limestone. This is composed of tabulate and stromatoporoid corals and is succeeded by jointed shales filled with an abundance of rhynchonelloids. Another small coral reef follows and, after that, another mass of shales similar to those first described and with an equal paucity of fossils. Rhynchonelloids are very uncommon in the first and third shales; but extremely abundant in the shales between the coral masses, while large specimens of *Atrypa reticularis* are relatively common in the first and third sections of shales, but are hardly present in the second. All of this variation may be seen in less than fifty feet, and the strata in question are believed to be of the horizon of the Ilionia bed.

Another excellent place to observe horizontal lithic and faunal variations is at Hoburgen klint in the higher beds of reef and other limestones. In the klint the great unstratified masses of coral rise many feet, and are bordered on each side by stratified crystalline and other limestones of a quite different lithic and faunal aspect, the latter deposits filling up the irregularities in the sides of the former. The interfingering of coral and sediment and the irregular contacts are extremely striking and instructive. These latter strata generally dip away from the reef. Still another excellent place to study the variation in sediments is Burgen Ridge, on the northern side of which a mass of hard reef limestone is underlain by shaly reef and crinoidal limestone, this being limited below by the Dayia flags. On the southern side, on the contrary, the rock occupying exactly the same stratigraphic position consists of oölite and limestone conglomerate (Plate 5, fig. 2) with pebbles up to an inch in diameter, sandy limestone, and calcareous shales and limestones underlain by the lower Sphaercodium bed and the Dayia flags. On the northern side Sphaerocodium has not been noted. All of these variations occur in about one fourth mile. Another excellent locality is on the island of Storo Karlso where numerous fine exposures may be seen in the sea cliffs in which faunal and sedimentary variation are shown. Dozens of

[1] Munthe. Sveriges geologiska unders., 1902, ser. C. no. 192, p. 9.

other exposures present similar features, and the fact of such variation is altogether too evident to be opposed. It appears very doubtful if any single division is continuous without much variation over the entire island. This, and other features to be noted later, have made the stratigraphic determinations and correlations extremely difficult. Since changes in sediments are invariably accompanied by faunal changes the problem is one of great complexity and much difficulty.

Unconformities in the Gotland section. Discordances of strata are not uncommon in the Gotland section; but where seen by the writer they have no great significance and bear no other interpretation than that of contemporaneous erosion and refilling, that is, they were made by erosion of the sea-bottom during the times of deposition of the sediments, or they have been produced by the overgrowth of corals on sediments or the covering of reef growths by sediments. Some of the conglomerates which have been mentioned by various writers have been considered as evidence of a transgressing sea. Such conglomerates are present in great number, but they always occur as lenses and are always local. Many of the rocks which have been called conglomerates are certainly not such, since the "pebbles" have a concentric structure and are either of oölitic or organic origin. At any rate, these conglomerates bear no relation whatsoever to a transgressing sea. Holm [1] considers the probable existence of an unconformity at the top of the lower division whose summit is placed above the oölitic zone of southern Gotland, while Hedström mentions a discordance which is situated at about the same position, that is, between the Lower and Upper Gotlandian beds [2] and at about this same level the Silurian scorpion, *Palaephonus nuncius* Thorell and Lindström was discovered in association with marine forms. Holm thought that the presence of this land form bore on the question of discordance and the probability of a Middle Silurian land interval on Gotland,[3] but to the writer it fails to bear that, as the only, or even the probable interpretation. It might have attained the bottom of a shallow sea in many ways. It is by no means rare today to see land insects and other land organisms floating in the sea, and A. Agassiz states that "It was not an uncommon thing to find at a depth of over one thousand fathoms, ten or fifteen miles from land, masses of leaves, pieces of bamboo and of sugarcane, dead land shells, and other land *débris*, undoubtedly blown out to sea by the prevailing tradewinds. We

[1] Guide book 11th. internat. geol. congr., 1910, no. 19, p. 8. quoted by Munthe.

[2] Hedström. Guide book 11th. internat. geol. congr., 1910, no. 20, p. 9.

[3] Guide book 11th. internat. geol. congr., 1910, no. 19, p. 8, quoted by Munthe.

frequently found floating on the surface masses of vegetation, more or less water-logged, and ready to sink. The contents of some of our trawls would certainly have puzzled a palæontologist; between the deep-water forms of crustacea, annelids, fishes, echinoderms, sponges, etc., and the mango and orange leaves mingled with the branches of bamboo, nutmegs, and land shells, both animal and vegetable forms being in great profusion, he would have found it difficult to decide whether he had to deal with a marine or a land fauna." [1]

It is not improbable that similar conditions obtained in Silurian days. Eurypterids occur at about the same level, and their presence is susceptible of the same explanation, even if they were not themselves marine.

In the south of Gotland I do not consider that any evidence of an unconformity indicating a land interval is present nor was any seen in the waterfall section at Wisby, but the observations made at that section were not extensive, nor detailed. Hedström described a disconformity between the Lower and Upper Gotlandian in the precipice south of Gustafsvik, indicated by a "thin marly and gravelly water-worn layer, containing, amongst other things, worn Gastropods of the genera Trochus, Pleurotomaria, Horistomia etc.," and he has little doubt of the actual occurrence of erosion, but he does not state whether he considers this as indicative of a land interval.[2] I have not seen the locality and so can not give further data, but the presence of pebbles and worn shells may be equally well explained by contemporaneous erosion in a coral reef channel. It appears that the question of land in Middle Silurian time, within the present area of Gotland, remains to be proven, and the idea is favored that marine conditions prevailed over the present limits of Gotland throughout the time of deposition embraced between the youngest and oldest deposits.

Evidence of shallow water. That the Gotland rocks are the deposits of very shallow water is evidenced by the extraordinary development of coral reefs, the strongly developed edaphic modification shown by the fossil faunas, and the extensive lateral gradation of sediments. These show that the sea bottom was sufficiently shallow to closely respond to land conditions, and that there were numerous local barriers so near the surface as to produce a great variety of differing conditions. Among these local barriers the most important were the coral reefs which protected colonies within them and hindered migration over, or around them.

[1] Agassiz. Three cruises of the Blake, 1888, 1, p. 291.

[2] Hedström. Guide book 11th. internat. geol. congr., 1910, no. 20, p. 23, fig. 4.

The sandstone layers in the south of Gotland are extremely suggestive and interesting. They appear to grade northward into shales, suggesting that the source of the materials was southward. The sands are the deposits of quite shallow water, and are probably not wind and wave deposits of a shore, the absence of decided crossbedding rather strongly arguing against the latter view. They contain fossils only near the base and near the top and are overlain by oölites. The cleanness of the sands and the absence of crossbedding and fossils suggests the drift sand zone of Godwin-Austin, a deposit of fairly quiet water; while the overlying oölites with fossils could well have accumulated in the shallow water after either some extra-Gotland territorial physical changes or changes in the development of the coral reefs, modifying the direction of the currents, had caused the sand to cease to drift. A most important fact connected with the sandstone beds is that in the sea over southern Gotland they eliminated the corals during the duration of the deposition of the sands, and hence no coral reefs appear to pass through them.

The coral reefs. Many students have commented on the extensive development of the reefs of Gotland and they are well worthy of comment. They are present in practically every parish of the island, and the surface and shore topography of Gotland have been largely controlled by the fact of their occurrence, and these in turn to a large extent have influenced the past and the present activities of the Gotlanders. The organisms which played the greatest part in the development of the reefs belong to the Stromatoporoidea, and there are probably a half score of these for every colony of all the others put together. Crinoids also made great contributions to the material of the reefs. Some of the reefs are of large size. At Hoburgen klint one of them is fully one hundred and fifty yards wide and reaches from the oölite to the top of the cliff, a thickness of about seventy-five feet. The corals of the reefs are frequently little changed from their original condition, and in pockets between the coral growths are small masses of clay and sand which are remarkable for the excellent fossils which they contain. In general, the coral masses offer greater resistance to erosion than do the surrounding or underlying rocks, so that in the cliffs they project as salients or overhanging masses and in the fields as knolls, on the northward or stoss side of which, the side from which the ice came, the surrounding rock has all, or nearly all, been eroded away, while on the side opposite the direction of ice movement the protection of the coral masses has preserved to some extent the surrounding rock, which is generally a crystalline limestone. These

knolls are called by the people "Klintar," and they constitute the hearts of the elevations of the island. Probably the original summit of every one of these reef masses has been eroded away, as well as later rock which was deposited about their margins. In the cliffs the peculiar forms developed in the coral masses have led to various legends, as the "Old Man of Hoburgen," etc. Some of the coral colonies are quite large. At Hoburgen a single stromatoporoid colony which shows continuous growth, but has two included marl pockets, is ten and a half feet wide and eight feet high.

At Staffs klint, the reefs extend to and into the Marl shales, tending to show that at that place growth apparently was continuous from the times of Marl shale deposition up to, and probably beyond, the time of the deposition of the Spongiostroma bed, thus bridging the gap between the upper and lower divisions.

Interpretation of the Gotland Section.

Any interpretation of this famous section must recognize the importance of the coral reefs. They control the present shore and surface topography of the island and they must have exerted a large influence upon, even if they did not control, sedimentation, during the times of their development. What were the conditions under which they were built? It has been shown that at Hoburgen and Staffs klint, and could be shown in many other places, that they extend through many beds, and it is assumed that they grew more or less continuously while the sediments were depositing around them. A question of great importance in this connection is whether the rock of the coral reefs is of the same age as that of the other beds which at any particular level lie on their flanks. The conditions around modern coral reefs help to solve this problem. These, at least in many, and probably most instances, rise with steep slopes from deeper waters "and if elevated above the sea, they would stand as broad ramparts separated by passages mostly 20 to 200 feet deep." [1] Vaughan describes a like bottom topography about the Florida reefs, but the passages separating the reefs are "usually 9 to 12 feet" and "always less than 10 fathoms." [2] The surface of a modern coral reef is very irregular and "there are deep cavities among the congregated corals, in which a lead will sometimes sink to a depth of many feet

[1] Dana. Coral and coral islands, 1890, p. 389.

[2] Vaughan. Papers Tortugas laboratory Carnegie inst. Washington, 1910, 4, p. 109.

and even fathoms," [1] and these depressions of the surface afford lodging places to the multitude and variety of organisms, which live in, on, and about a growing coral reef, a variety of life to which attention has been called by nearly every student of coral reefs.

Many feet, in the vertical sense, may and usually do separate the upper surface or summit of a coral reef from the bottom of the sea about the margin, while the horizontal distance between the summit of the reef and the bottom is usually not great. Conditions of this nature make it possible for individuals of the same species to live on top of the reef among the coral colonies and also twenty-five to a hundred feet lower down only a few feet distant horizontally, and it is certain that some of the shells of animals living on the top will be washed into lower waters by the waves which dash over the reef during high tide or during storms. Since variation of depth up to one hundred feet is not sufficient to control the distribution of a great number of species of marine organisms, it follows that many species will thrive in multitudes on the top of the reef and over the adjacent bottom.

Ultimately the reef may and probably will become surrounded with sediments of an age somewhat younger than that of the reef on the same level with itself. Stating the matter differently, *the rocks composing the reefs would have their time equivalents in strata holding a lower vertical position in the section.*

Exactly similar conditions must have obtained among and about many, if not all, of the ancient coral reefs and the writer is quite positive that they existed in connection with the reefs of Gotland, which stood above the bottom as is proven by the fact that cases are visible where coral colonies have fallen from the sides of the reefs to a lower level. That the tops of these elevations were irregular and filled with deep and shallow holes is shown by the included masses of clay, many of which are filled with excellently preserved fossils.

If the organisms of this sea were distributed over this sea bottom both upon the tops of the reefs and the lower levels about their margins there should be some evidence of this distribution in the existing fossils. In this consideration the distribution of the corals themselves has no validity, because in the cases of most of them they range more or less throughout the entire section. The chief reliance has been placed on the brachiopods. The natural stratigraphic position of *Bilobites bilobus* (Linné) is in the lower half of the Gotland section, but near

[1] Dana. Loc. cit., p. 145.

Etelhem Dr. Henry Munthe collected this species[1] on the summit of one of the knolls of the Ascoceras limestone which are so abundant in that region, while on the summit of another knoll of the same region I collected *Conchidium conchidium* (Dalman), *C. biloculare* (Linné) in the midst of a coralline limestone of the Ascoceras type, and on Storo Karlso *Pentamerus estonus* Lindström and *Conchidium conchidium* occur in association in the midst of coralline limestones belonging to the rocks of the highest part of the island. *Orthis rustica* Sowerby is another species which can be found far above its natural stratigraphic position in the midst of the highest rocks of the island, the writer having collected it in clay pockets in the coral reef at Hoburgen.

It has been quite generally considered that the highest rocks of Gotland are the youngest, yet we find therein species whose natural stratigraphic positions are lower in the section. I believe that the high coralline rocks of Gotland are not the youngest of that island, that they are older than any rock (there are a few exceptions) which lies at the same level on their flanks, and that the coralline rocks should be correlated with strata holding a much lower level. A recent letter from Dr. Munthe shows that he is coming to the same conclusion for he says, writing under date of October 2, 1915, "Last summer I have ascertained that the 'Marl Shales' (Lindström's bed e) are synchronous with a part of the reef-limestone ('Ascoceras limestone in part') in Garde etc." I believe the conditions are something like those represented in Figure 1.

Conditions like these make local correlation extremely difficult, and when one considers that collections have been made without a recognition of the possibility of their occurrence, it is readily seen to what extent extra-Gotland correlation would be complicated. It is believed that in this way are explained a great many of the various difficulties which have arisen in connection with the Gotland section.

Assuming, then, that the corals stood above the bottom and rose to or nearly to the surface of the water, it follows as a consequence that during the period of the development of the reef that it grew upward much more rapidly than the sediments accumulating around it. Later, however, when the reef reached the surface of the water its rapid growth ceased,[2] and sediments accumulated around it far more rapidly than it grew upward, the coral reef providing through its

[1] Personal communication.

[2] This statement assumes that there was no sinking of the sea-bottom. If the sea-bottom were sinking, growth upward would continue until the downward movement ceased, after which the conditions described would obtain.

attempted upward growth a part of the materials composing the sediments. It became possible, then, for very small thicknesses or even small patches of material in the upper portion of a reef to represent considerable thicknesses of the sediments which were accumulating on the flanks of the reef. Stating the matter differently, in the early stages of reef development, great thicknesses of unstratified reef limestone should be represented by much thinner masses of stratified

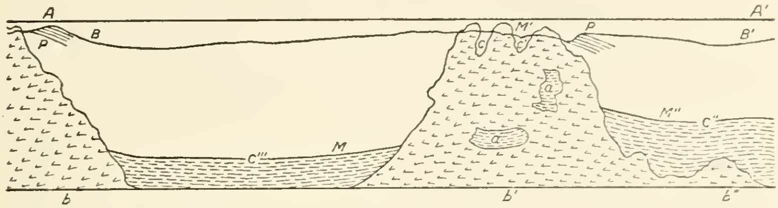


Figure 1.— Diagram showing possible conditions in and about a coral reef. The line A–A′ represents sea-level during the development of the reef and the deposits about it. The line B–B′ represents the present surface. Sediments other than those of the reef are stratified. The unmarked portions of the reef above the present surface are assumed to have been eroded away after uplift had taken place. Unmarked portions between the present surface and the former sea-bottom, M and M″, are assumed to be filled up with sediments which were developed after the reef was formed and hence are younger than the reef.

M–M″ are deposits of the same age. On the margins of the reefs the stratification is inclined.

C–C″ are colonies of the same species of organism on the reef and adjacent bottom. Sediments containing the shells of these species will be of the same age, but the reef rock on each side and above the colonies of the reef is older than the sediments which fill the cavities.

b″ represent the base or beginning of a coral colony.

a–a′ are stratified sediments within the reef. The time equivalents of these sediments are below M and M″.

P–P are outcrops of inclined stratified rock with everything else, other than some exposures of the reef rock, hidden. The exposures might readily lead to the conclusion that the reef on the left is older than that on the right, and that the strata are progressively younger toward the right or, if the fossils indicated otherwise, that a fault lay between the two reefs.

limestone lying at a lower level, and, after the reef reaches the water-level, almost negligible thicknesses of reef limestone should find their equivalence in much thicker beds of stratified limestone, also at a lower level. Further, in all the stages of reef development the later animals would live above the shells of the earlier animals, and also in the hollows of the reef below them, and when the whole became turned into stone the shells of different times would become almost hopelessly mixed.

If the above arguments have validity, and I am firmly convinced that they do, it follows that little weight can be attached to coral reef faunas in attempting correlation.

In the channels between modern reefs varied conditions obtain, and Dana describes the deposits as variable to a high degree, at one place coral sand, at another coral mud, at others clay mud with little coralline material and he states that "The facts show that the rocks formed in such channels may be of all the kinds that occur in reef regions — coral and shell conglomerate, compact impalpable limestone, limestone full of Orbitolites, or containing, as well, remains of other species of the seas, and also rocks made of clay, mud, sand or pebbles of the mountains or high lands adjoining."[1]

As illustrative of the data given in the above quotation Dana might have cited the reefs of Gotland, as every word is strictly applicable. There, on the same level, are fine-grained limestones made from lime muds, limestone conglomerates, lime sandstones, clays, shell breccias, etc. In the passages between modern reefs the "tidal currents often have great strength, and are much modified and increased in certain places, or diminished in others, by the position of the reef with reference to the lands"[2] and there is little doubt that local erosion replaces deposition to a considerable extent as the growth and erosion of the reefs change the direction of the currents, thus developing local unconformities. In this way the many discordances of the Gotland section are readily explained.

These varied conditions upon, within, and about a coral reef will be and are reflected in the faunas of the bottom, each species selecting that bottom and those conditions on and under which it best thrives, and animals of the same species might be found on the top of the reef and at its foot, as, for example, might have occurred (and where it is believed it did occur) at Hoburgen where about seventy-five feet separate the existing summit from the base.

The sediments which are deposited on the flanks of a coral reef, or any similarly elevated mass, are inclined away therefrom. The compacting of the strata would increase the inclination while local slumping would intensify the undulatory structure. As a consequence anticlinal and synclinal structures would be developed. Some of the undulations of the Gotland section may, and appear to have been developed by subsequent movement, but it is certain that many are contemporaneous and are directly referable to the influence of the

[1] Dana. Loc. cit., p. 152.
[2] Dana. Loc. cit., p. 151.

coral masses. Some of them may also have been subsequently formed by the settling of the sediment over the coral ridges, which would remain rigid while that filling the basins on each side would settle. At any rate, few or none of these inclinations and undulations have any significance in connection with the stratigraphic relations.

Among coral reefs the strata in the different channels are more or less isolated, and they would dip away from the reefs in a way that would appear to carry them far below other strata in the direction of inclination, and if this basin or synclinal-like structure could not be discerned the conditions would lead to divergent interpretations. I do not wish to argue that younger strata are not present in the southeastern part of the island, nor that strata of the same age occur over all parts of the island. I believe the truth lies between the two extremes, but wish to emphasize the fact that in each of the channels between the reefs there will be apt to be a different lithology, a different structure, and a different fauna from that in any other channel. Since the rate of deposition in each channel will be different from that in another, it follows that strata of a certain time interval will lie in one channel at a higher or lower level than that of another channel, and each will be below the rock of the reef which represents the same time interval.

That to a considerable degree, the conditions described represent those obtaining in the Gotland section I feel assured. These views open a most interesting field for investigation, which should be begun by a careful mapping of every coral reef which can be discovered on Gotland, and this should be followed by a careful study of the inclinations of the strata, and these should also be mapped in order to see the relation of these inclinations to the coral reefs. Then the deposits and fauna of each basin between the reefs should be studied in an endeavor to correlate the strata of the different basins. When this is done the controversy as to whether certain strata on one side of the island lie underneath or above certain strata on the other side will have disappeared, and data will have been collected upon which something besides hypothesis can be erected. The detailed work that Drs. Munthe and Hedström are doing is laying the foundation to the ultimate untieing of this Gordian knot of Baltic stratigraphy.

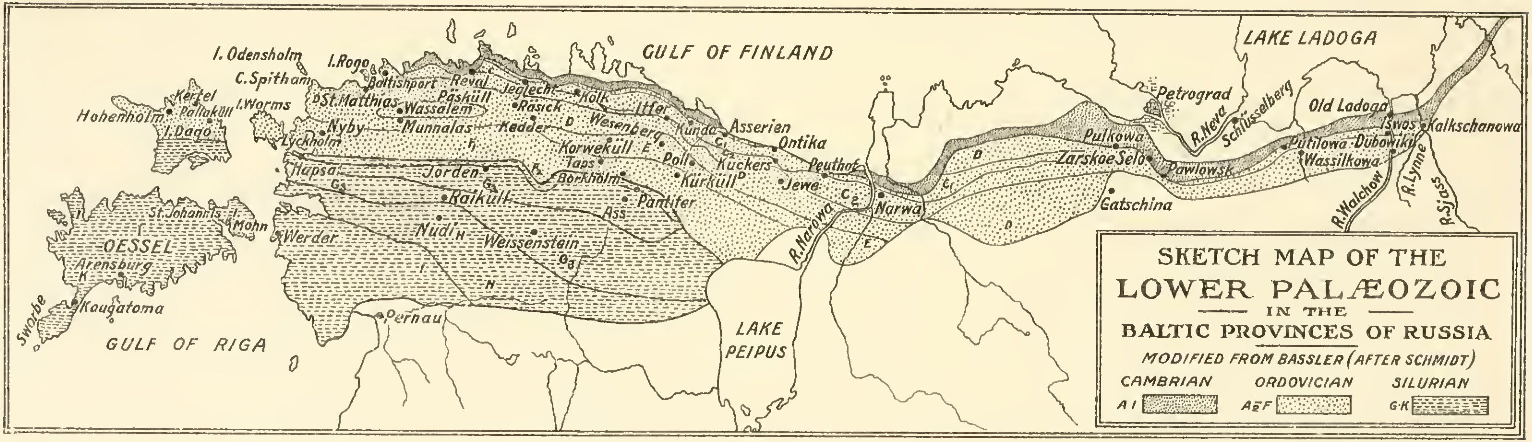
CONCLUSIONS.

1. The coral reefs exercised a controlling influence in the development of Gotland lithology and stratigraphy.
2. Little reliance can be placed on coral reef faunas in correlation, since species of different horizons are apt to occur in association.
3. The fauna of any basin about a coral reef is apt to exhibit many differences when compared with the fauna of another basin.
4. Discordances of strata are readily developed in sedimentation about coral reefs and have little or no significance.
5. Conglomerates and worn shells should be present in deposits about coral reefs, and neither indicates a transgressing sea nor a land interval.
6. Directional and quantitative variations of inclination of strata have wide limits about coral reefs, and should always be considered in coral reef stratigraphy.
7. In general, the rock of any reef is older than that lying at the same level on its flanks.
8. Strata of the same time interval will lie at different elevations in the different channels between the reefs.
9. The ultimate solution of the problems of Gotland stratigraphy will probably be reached by a study of the relations of the sediments and the faunas to the coral reefs.

PLATE 1.

PLATE 1.

Sketch map of the Lower Palaeozoic in the Baltic Provinces of Russia.


SKETCH MAP OF THE
LOWER PALÆOZOIC
IN THE
BALTIC PROVINCES OF RUSSIA
MODIFIED FROM BASSLER (AFTER SCHMIDT)
CAMBRIAN
ORDOVICIAN
SILURIAN
A I
A2 F
G-K
GULF OF FINLAND
LAKE LADOGA
GULF OF RIGA
LAKE PEIPUS
I. Odensholm
C. Spitham
I. Rogo
Baltishport
Reval
Jeglecht
Kolk
Petrograd
R. Neva
Schlüsselberg
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Iswos
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I. Worms
Kertel
Pallaküll
Hohenholm
I. Dago
St. Johannis
I. Mohn
OESSEL
Arensburg
Kaugatoma
Sworbe

PLATE 2.

PLATE 2.

Fig. 1 — Quarry face in the Lower Lyckholm at Palloküll, Esthonia.
Fig. 2.— Cliff of the Upper Lyckholm at Pirk, Esthonia.

1

2

PLATE 3.

PLATE 3.

Fig. 1.— Contact between the Jörden Schicht and the *Pentamerus borealis* banks at Jörden, Esthonia. The type-section.

The hammer is on the line of division. The spots in the upper strata are the shells and molds of *Pentamerus borealis*.

Fig. 2.— Quarry face in the Raiküll formation at the type-locality in Esthonia.

1

2

PLATE 4.

PLATE 4.

Fig 1.— East side of the Island of Storo Karlso off Gotland, Sweden, showing the strata dipping into the sea.

Fig. 2.— West side of Storo Karlso showing the strata dipping west.

1

2

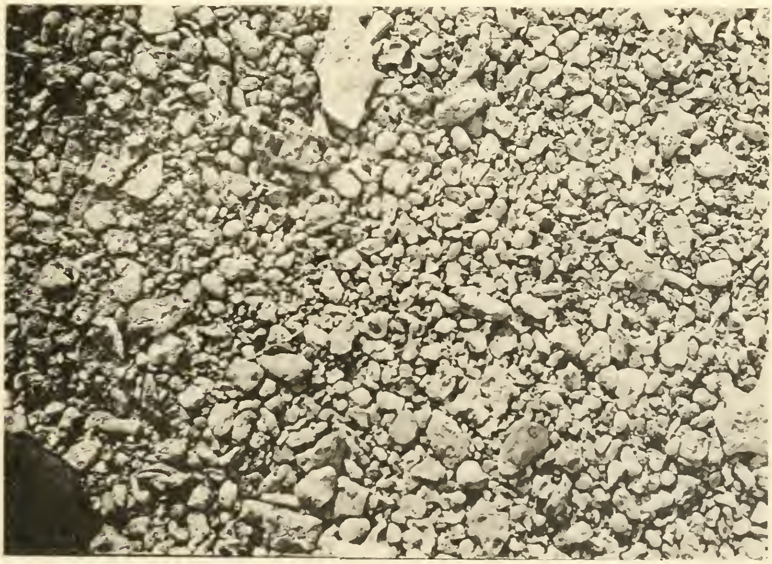
PLATE 5.

PLATE 5.

Fig. 1.— South side of Storo Karlso showing great variation of inclination in the vicinity of small reef-like masses of coral.

Fig. 2.— Limestone conglomerate on the south side of Burgen Ridge, Gotland. Nearly all the pebbles are rounded and show great wear. A few years appear to suffice for the rock to disintegrate. The coral reef is in the heart of the ridge. The camera was held about three feet above the ground.

1



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